Investigation into the Abrasion Resistance of Polyurea Coating by the Taber Abraser

by

Azmal Khuzairi Bin Abdul Wahab

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

May 2010

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

____

(Mr. Muhamad Ridzuan Abdul Latif)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

AZMAL KHUZAIRI BIN ABDUL WAHAB

ABSTRACT

Polyurea coatings is a relatively new class of industrial coating, usually applied by spray using specialised equipment and characterised by extremely fast drying and high performance. Polyurea's strength are tailored to fill the gaps left traditional coating products used in the oil and gas industry and is the ideal coating product for the oil and gas industry's especially for pipelines. The abrasion wear resistance for this coating is highly demanded and it relate with the surface preparation which is one of the main focus to maintain the abrasive wear resistance. To achieve good coating, steel substrate must have proper roughness in order to provide an increased effective surface area for mechanical bonding. This roughness, also known as anchor pattern or surface profile, forms micro pattern of peaks and valleys at the surface, which can be obtained via solvent cleaning methods and hand and power tool methods when an abrasive blast cleaning is not practical due to limited accessibility.

The objective of the project is to determine the abrasion wear resistance of the polyurea coating and the next objective is to vary the different kind of surface preparation with the surface roughness on the coating. The abrasion resistance is determining by using Taber Abraser Machine and also using with the surface profiler machine to get the data for the surface roughness. The test is done according to the standard which is ASTM D 4060-95: Standard Test Method for Abrasion Resistance of Organic Coatings by Taber Abraser.

From the data collected, it is observed that the two different surface preparations which is by Hand and Power Tool, St 3 and by Solvent Cleaning, SP 1; show some variation that effect on the abrasion wear resistance. This observation is based on the surface roughness that gives the data for average roughness on the surface, Ra. An essential feature of any coating system is the bond between the coating and the substrate. For successful coatings, the substrate surfaces needs to rough and pitted to provide a "foot-hold" (Splat-Hold) for each splat of coating that impacts the substrate.

ACKNOWLEDGEMENT

First of all, my deepest gratitude to Allah SWT, the Lord of Universe for his blessings and guidance in various aspects for me to accomplish my final year project entitled '*Investigation into the Abrasion Resistance of Polyurea Coating by the Taber Abraser'*. Special thanks to my parents and family members for their continuous support and encouragement towards me all this while in completing this project.

This Final Year Project has given me lots of useful knowledge and experience n preparing myself to the next stage of life which is career life. First and foremost, I wish to thank my Supervisor, Mr. Muhamad Ridzuan Abdul Latif for his valuable advice, nonstop guidance, motivational support and positive criticism to me which has helped me a lot, right from the start of this project until I am finally able to complete this project. He has driven me beyond my preconceived limits which enabled me to discover my new strengths and capability thus make this project a success.

A high appreciation to all Mechanical Department technicians especially Mr. Faizal and Mr. Irwan for their assistance in all the experiments carried out to complete this project. This project would never been a success without support and technical assistance from all of them.

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Without all of them, I would not have been able to accomplish and meet the objective of this project in total.

Hopefully this project will provide the readers with more knowledge and understanding towards organic coating especially in polyurea development.

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ABBREVIATIONS AND NOMENCLATURES

SSPC	**Steel Structure Painting Council**
ISO 8501-1	**Preparation of Steel Substrates before Application of Paints and Related Products – Visual Assessment of Surface Cleanliness**
BS 4232	**British Standard Institution**
ASTM 4060-95	**Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abrader**
SP 1	**Solvent Cleaning**
St 3	**Hand and Power Tool Cleaning**
SEM	**Scanning Electron Microscopy**

CHAPTER 1

INTRODUCTION

1.1. BACKGROUND OF STUDY

Polyurea coatings technology is one of the new developments of the last 20 years. This technology combines fast curing, even at low temperatures, and water insensitivity with exceptional mechanical properties, chemical resistance and durability. A polyurea coating is the result of a one-step reaction between an isocyanate component and a resin blend component [Marc Broekaert, 2003, *Polyurea spray coatings*].

Polyurea coatings combine extreme application properties such as rapid cure, even at temperatures well below 0^oC, and insensitivity to humidity, to exceptional physical properties such as high hardness, flexibility, tear strength, tensile strength, chemical and water resistance. The result is good weathering and abrasion wear resistance [Marc Broekaert, 2003, *Polyurea spray coatings*]. Coating on substrates can be damaged by abrasion during manufacturing and service [2001, *Annual Book of ASTM Standards*, *Section 6*]. The abrasion wear resistance is the ability of a material to withstand mechanical action such as rubbing, scraping, or erosion, which tends progressively to remove material from its surface. It is such ability helps to maintain the material's original appearance and structure.

This abrasion wear resistance of coating is typically depends on the surface preparations which is a mechanical (interlocking) bond. An essential feature of any coating system is the bond between the coating and the substrate. The test method that has been useful and similar in evaluating the abrasion resistance is by ASTM D 4060-95. This test method is for Abrasion Resistance of Organic Coatings by the Taber Abraser.

1.2 PROBLEM STATEMENT

At early stage, polyurea was used as a protective layer over polyurethane insulation foam for roofing applications. The broad window of application conditions, with a high tolerance for humidity, both from the environment and from the substrate, and temperature, makes polyurea a very suitable coating for metals in offshore applications like pipe protection, inner pipe repair, tank coatings, bridges and platform [*Steel Surface Preparation*, http://www.maspaints.com/, Retrieved August 29, 2009, 8.11pm]. To be able to define the right applications, a good understanding of the properties of polyurea coatings is needed.

Based on a general overview of the physical and chemical properties, this polyurea coating are known to be very tough. The combination of high resistance with high surface preparation can give a result in an abrasion wear resistance. Coating applied using this polyurea processes typically depend on a mechanical (interlocking) bond. The nature of the substrate surface is therefore a key to quality the polyurea coating. To achieve good coating, steel substrate must have proper roughness in order to provide an increased effective surface area for mechanical bonding.

This roughness, also known as anchor pattern or surface profile, forms micro pattern of peaks and valleys at the surface, which can be obtained via power-tooling methods and hand and power tool methods when an abrasive blast cleaning is not practical due to limited accessibility. For successful coatings, the substrate surface needs to rough and pitted to provide a “foot-hold” (Splat-Hold) for each splat of powder that impacts the substrate. In addition, the surface needs to be clean and free from contamination that would fill the pits and prevent locking of the splats.

Two types of surface preparation solvent cleaning and hand and power tool cleaning were tested and evaluated in terms of surface profile and subsequent coating performances due to the abrasion resistance of the coating.

1.3 OBJECTIVES AND SCOPE OF STUDY

The objectives are:

- To determine the abrasion wear resistance of the polyurea coating by using the taber abrader machine.
- To study the different effect of surface preparation on the wear resistance of polyurea coating.

The scope of study:

In this study, the steel use as a substrate to give the same impact and affect to the industrial applications. The polyurea coating is coated at the surface of steel within the tolerance that to be set about ± 1mm. The other thing to be followed in this project is the surface preparation for the steel as a substrate. There are two different types of surface preparation to be computed at the end of this project which Hand and Power Tool Cleaning (St 3) and the other one is Solvent Cleaning (SP 1). The load and cycle use in this project: loads – 1000g and the cycles – 1000 cycles. The last part is to study the surface profiles and roughness by using the Surface Profiler machine and compare it with two different types of surface preparation on the steel as a substrate. The sample also is weight by using the Digital Weight Scale. The coating sample is set to be inspected by using dry coating thickness gauge to get the same thickness. The Taber Abraser Machine is used to determine the Abrasion Wear Resistance by follow the ASTM 4060 standards.

CHAPTER 2

LITERATURE REVIEW

SIGNIFICANCE AND USE

Coating on substrates can be damaged by abrasion during the manufacturing and service. This test method has been useful in evaluating the abrasion resistance of attached coatings. Ratings produced by this test method have correlated by the falling abrasive values in *Test Method D 968* [2001, *Annual Book of ASTM Standards*, *Section 6*].

2.1 SURFACE PREPARATIONS

The life and performance of any paint system depends directly upon surface preparation. About 60% of all coating failures are due to improper surface treatment [*Steel Surface Preparation*, http://www.maspaints.com/, Retrieved August 29, 2009, 8.11pm].

For any given paint system, surface preparation is the single important factor which would determine its performance. Various surface preparation methods are adopted depending on the requirements of the paint system used and the substrate. The substrate could be steel, galvanized steel, aluminium, concrete or wood [*About Paints* http://www.nationalpaints.com/aboutPaints, Retrieved August 15, 2009, 8.56pm].

2.1.1 STEEL AS SUBSTRATE

Various methods of surface preparation are adopted by degreasing, high pressure fresh water hosting, hand tool cleaning and power tool cleaning. Degreasing is done to remove all oil and grease prior to manual or blast cleaning. The most common method is by solvent washing followed by wiping dry with clean rags. A suitable detergent solution can also be made use of, which has to be subjected to fresh water hosing to remove traces of detergents [*About Paints* http://www.nationalpaints.com/aboutPaints, Retrieved August 15, 2009, 8.56pm].

The following are the most important surface preparation standards commonly followed worldwide:

1. Swedish Standard SIS 05 59 00 – (1967 – Pictorial Surface Preparation Standards for Painting Steel Surface)
2. Steel Structures Painting Council (*SSPC*), USA
3. British Standards Institution – Surface Finish of Blast Cleaned Steel for Painting (*BS 4232*)
4. International Standard ISO 8501-1 : 1988

Proper surface preparation is essential for the success of any protective coating scheme. The importance of removing oil, grease, old coatings and surface contaminants (such as millscale and rust on steel, laitance on concrete and zinc salts on galvanized surfaces) cannot be over emphasized [International Protective Coatings, 2009, *Surface Preparation.pdf*].

The performance of any paint coating is directly dependent upon the correct and thorough preparation of the surface prior to coating. The most expensive and technologically advanced coating system will fail if the surface preparation is incorrect or incomplete [International Protective Coatings, 2009, *Surface Preparation.pdf*].

Please refer to **Appendix 2-1** for Surface Preparation as per PTS, **Appendix 2-2** for Surface Preparation as per SSPC and **Appendix 2-3** for Surface Preparation according to ISO 8501-1.

2.1.2 SURFACE PROFILE/AMPLITUDE

The type and size of the abrasive used in blast cleaning have a significant effect on the profile or amplitude produced. In addition to the degree of cleanliness, surface preparation specifications need to be considering ‘roughnesses relative to the coating to be applied. For example, shot abrasives are used for thin film paint coatings such pre-fabrication primers, whereas thick or high build paint coatings and thermally sprayed metal coatings need a coarse angular surface profile to provide a mechanical key. Inadequate quality control and lack of restriction of large abrasive particle sizes for thin priming coats can lead to peaks of the blast cleaned surface not being adequately covered and may produce rust spots very quickly. The more recently used very high build coatings and thermal –sprayed metal coatings need a large surface area with a high profile in order to ensure that the adhesive bond is greater than the cohesive bond [*Surface Preparation for Coating,* http://resource.npl.co.uk, Retrieved August 10, 2009, 9.15pm].

2.2 ABRASION WEAR RESISTANCE

2.2.1 TYPES OF WEAR

Wear – Damage to a solid surface, generally involving progressive loss of material, due to relative motion between that surface and a contacting substance or substances. **Abrasive wear** – Wear due to hard particles or hard protuberances forced against and moving along a solid surface. These hard particles might be commercial abrasives like silicon carbide and aluminum oxide, or naturally occurring contaminates like dust particles and sand [crystalline silica (quartz)]. If the abrasive particles are allowed to roll, rolling abrasion or three-body abrasion occurs. **Sliding wear** – Wear due to the relative motion in the tangential plane of contact between two solid bodies. Typically recognized by linear grooves that are generated from a reciprocating or unidirectional contact. **Rolling wear** – Wear due to the relative motion between two non-conforming solid bodies whose surface velocities in the nominal contact location are identical in magnitude, direction and sense.

Three-body wear – A form of abrasive wear in which wear is produced by loose particles introduced or generated between the contacting surfaces**. Two-body abrasive wear** – A form of abrasive wear in which the hard particles or protuberances that produce the wear of one body are fixed on the surface of the opposing body [*Materials Test and Measurement, Applications – Abrasion / Wear Testing,* http://www.taberindustries.com/applications/, Retrieved May 14, 2010 11.21am].

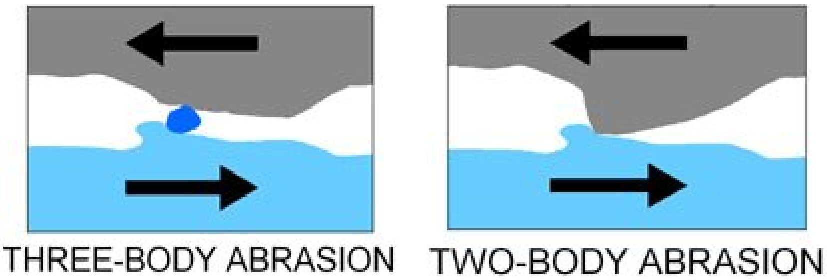


Figure 2.1: The Three-Body Abrasion and Two-Body Abrasion

2.2.2 UNDERSTANDING WEAR

For many products, it is easy to identify something that is worn. But understanding how it got to that state is not as simple! ASTM International defines wear as "damage to a solid surface (generally involving progressive loss of material), caused by the relative motion between that surface and a contacting substance or substances". In most instances, the material removal is a gradual process and the motion is a repetitive action.

Wear is a complex phenomenon that is influenced by many parameters. These include, but are not limited to:

1. Contact geometry,
2. Length of exposure,
3. Interacting material surfaces,
4. Normal force-sliding speed,
5. Environmental conditions,
6. Material composition and hardness.

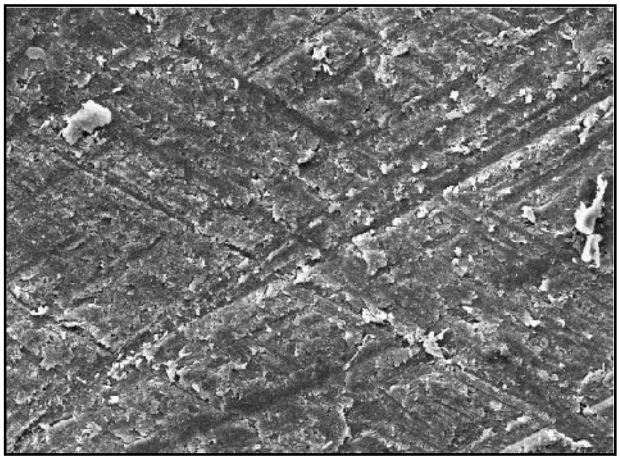


Figure 2.2: Surface Profile under the SEM for Abrasion Wear Resistance

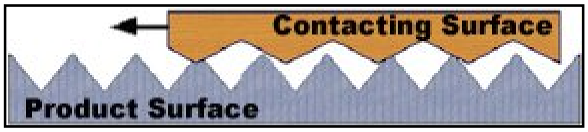


Figure 2.3: Process of the Wear Abrasion Resistance

The terms wear and abrasion are frequently used interchangeably, but there is a difference. Abrasion is the action that causes wear, and defined by ASTM as "the wearing away of any part of a material by rubbing against another surface". Wear abrasion is removal of a portion of the surface by some kind of mechanical action: rubbing, sliding back and forth of an object, wear of tires on traffic paint, wind erosion, and so on. Mar abrasion is the permanent deformation of a surface but the deformation does not break the surface [*Materials Test and Measurement, Applications – Abrasion / Wear Testing,* http://www.taberindustries.com/applications/, Retrieved May 14, 2010 11.21am].

2.3 POLYUREA COATING

Polyurea cannot solve the protective coating or joint fill needs by itself. It must be specified and installed in combination with proper surface preparation and primers, correct manufacturer's material formulation, proper equipment, quality control inspection and trained applicators [*All about Polyurea,* http://www.polyurea.com/ Retrieved September 29, 2009, 12.15pm].

Users and specifiers must take into consideration that the *proper combination of formulation, spray equipment, surface preparation, primers, training and application procedures* is what leads to **polyurea success**.

Improper training, under-rated equipment and lack of material/substrate compatibilities and preparation are what lead to polyurea failure, and for that matter, failure of any protective coating and lining system [*All about Polyurea,* http://www.polyurea.com/ Retrieved September 29, 2009, 12.15pm].

2.2.1 THE DEFINITION of POLYUREA

The term **'polyurea'** has been wrongly used in the past. The urethane coatings chemistry can be divided into three sub segments: i) polyurea coatings (Figure 2.1) [Marc Broekaert, 2003, *Polyurea spray coatings*].

I. A **polyurea** coating is the result of one-step reaction between an isocyanate component and a resin blend component. The isocyanate can be monomer based, a prepolymer, a polymer or a blend. For the prepolymer, amine- and/or hydroxyl- terminated resins can be used. On the other hand, the resin blend should only contain amine-terminated resins and/or chain extenders and not any hydroxyl reactive polymer components. All the polyurea coatings mentioned in the paper comply with this requirement [Marc Broekaert, 2003, *Polyurea spray coatings*].

Chemical reactions:-

1. Reaction with polyether amine:-

   $R - NCO + R' - NH_2 \rightarrow RNH - CO - NH - R'$

   (UREA)

2. Reaction with polyol:-

   $R - NCO + R'' OH \rightarrow RNH - CO - O - R$

   (URETHANE)

3. Reaction with water:-

   $R - NCO + H_2O \rightarrow R - NH_2 + CO_2$

   $R - NCO + R - NH_2 \rightarrow RNH - CO - NH - R$

   (UREA)

2.2.2 THE NEW TECHNOLOGY:

Polyurea spray coatings technology is one of the new developments of the last 20 years. This technology combines *fast curing*, even at a very *low temperatures*, and *water insensitivity* with exceptional *mechanical properties*, *chemical resistance* and *durability*. The development of new raw materials and improved spray equipment has made it possible to overcome the initial problems of this technology such as *substrate wetting*, *intercoat adhesion* and *surface finish quality* [Marc Broekaert, 2003, *Polyurea spray coatings*].

Polyurea coatings combine extreme application properties such as rapid cure, even at temperatures well below 0^oC, and insensitivity to humidity, to exceptional physical properties such as high hardness, flexibility, tear strength, tensile strength, chemical and water resistance. The result is good weathering and abrasion resistance [Marc Broekaert, 2003, *Polyurea spray coatings*].

2.2.3 THE DEVELOPMENT of POLYUREA

Product development within the industry has been ongoing with present formulation allowing for applications without added heat or high-pressure (as original formulations required) resulting in the present formula option of high-pressure spray, low-pressure spray, injection, pour and even brush and roll-grade formulations now widely available [*Pipe Coating Comparison,* http://www.nukoteasia.com/site/pdf/pipe_coating_comparison.pdf –, Retrieved September 29, 2009, 1.25pm].

High-pressure formulations that require heat and pressure to initiate curing remain the product types that provide the highest physical properties of any pure polyurea product and are most often specified in applications where strict compliance with specified properties is required. See Figure 2.2 for an example of typical high-pressure, plural component equipment used for application of high-pressure polyureas [*Pipe Coating Comparison,* http://www.nukoteasia.com/site/pdf/pipe_coating_comparison.pdf –, Retrieved September 29, 2009, 1.25pm].

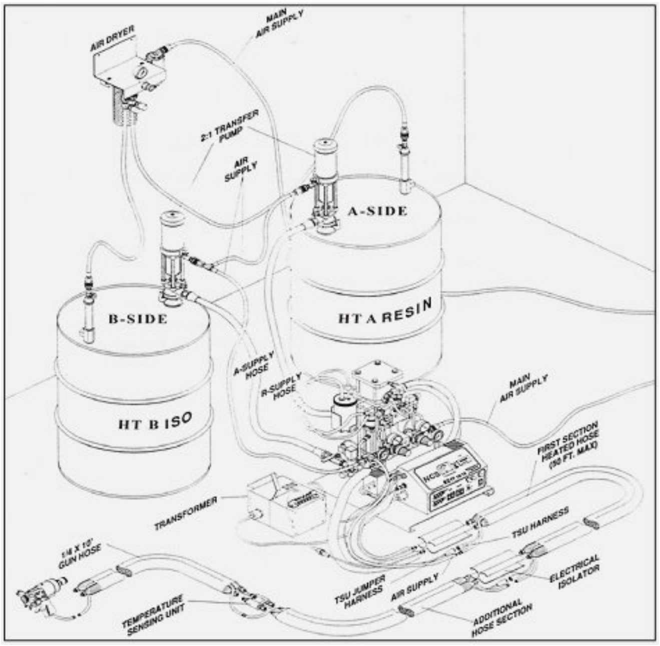


Figure 2.4: High Pressure Equipment

2.4 SURFACE ROUGHNESS

2.3.1 Roughness Parameters

i. Mean Roughness

The **Mean Roughness (*Roughness Average* Ra)** is the arithmetic average of the absolute values of the roughness profile ordinates. Ra is one of the most effective surface roughness measures commonly adopted in general engineering practice. It gives a good general description of the height variations in the surface. The units of Ra are micrometers or micro inches [*Roughness Parameter,* http://rubert.co.uk/Ra.htm, Retrieved September 29, 2009, 2.05pm].

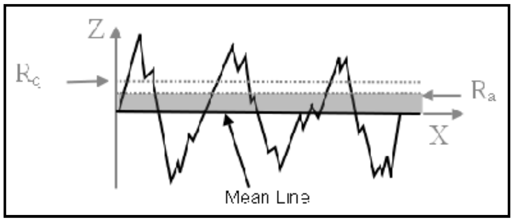


Figure 2.5: Roughness average, Ra

ii. **Roughness Depth**

The **Single Roughness Depth (Rz_i)** is the vertical distance between the highest peak and the deepest valley within a sampling length. The **Mean Roughness Depth (Rz)** is the arithmetic mean value of the single roughness depths of consecutive sampling lengths. The **Maximum Roughness Depth (Rmax)** is the largest single roughness depth within the evaluation length. The units of Rz are micrometers or micro inches [*Roughness Parameter,* http://rubert.co.uk/Ra.htm, Retrieved September 29, 2009, 2.05pm].

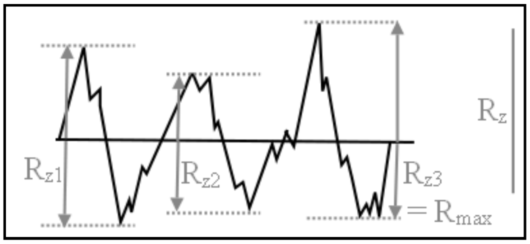
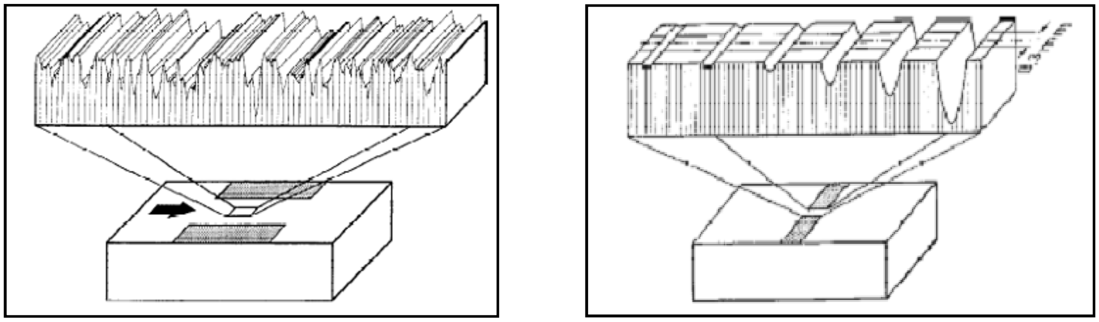


Figure 2.6: Roughness Depth, Rz

Table 2.1: **Precision Reference Specimens**

Item Number	ISO Type	Parameter Values	Roughness Values	Shapes	Profile
501	D	n/a	Ra = 0.02 µm = 0.8µ in	8 x 0.4 mm random	
502	D	n/a	Ra = 0.03 µm = 1.2µ in	4 x 1.25 mm random	
503	D	n/a	Ra = 0.1 µm = 4.0µ in	4 x 1.25 mm random	
504	D	n/a	Ra = 0.15 µm = 6.0 µ in	4 x 1.25 mm random	



(a) **(b)**

Figure 2.7: (a) Surface roughness standard-Type D

(b) Groove depth standard -Type Aq1

2.3.2 Measurements

- **Ra: Arithmetic mean deviation of the assessed profile:** arithmetic mean of the absolute ordinate values Z(x) from the mean line within a sampling length.
- **Rz: Maximum height of profile:** average height of the largest profile peak height Zp and the largest profile valley depth Zv over a sampling length.
- **Rmax: Maximum height of profile:** largest profile peak height Rz within a sampling length [*Roughness Parameter,* http://rubert.co.uk/Ra.htm, Retrieved September 29, 2009, 2.05pm].

CHAPTER 3

METHODOLOGY

3.1 MATERIAL

Stainless steel with thickness of 1.4mm is selected as the tested material for this research.

3.1.1 SAMPLE PREPARATION

Rigid material, in this case stainless steels are generally mounted to the standard specimen holder without the Clamp Ring (E100-102). It requires a 6.5mm (¼") center hole, which is drilled in order to mount it on the specimen holder. It is also possible to test the specimen without a center hole by using the S-37 or S-37-1 Mounting Sheets and the Drive Pin Type Holder (E140-19) [*Materials Test and Measurement, Applications – Abrasion / Wear Testing,* http://www.taberindustries.com/applications/, Retrieved August 10, 2009 11.21pm].

Figure 3.1: Test Sample

The test sample as shown in Figure 3.1; shall be a disk 4 in. (100mm) in diameter or a plate 4 in. (100mm) square with a 1/4 –in. (6.3mm) hole centrally located on each panel. Prepare a minimum of 4 sample plates for the material using two different surface preparations [2001, *Annual Book of ASTM Standards*, *Section 6*].

3.1.2 SURFACE PREPARATION

Proper surface preparation is of great importance in obtaining the optimum film performance. This step describes the initial surface preparation for steel plates, secondary surface preparation for fabricated steels, and the application of repair paint [*Surface Preparation*, www.wilckens-baltic.com/, Retrieved August 23, 2009, 3.30pm].

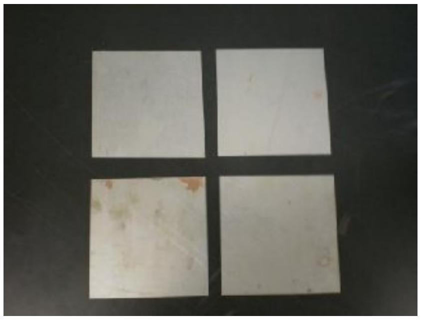
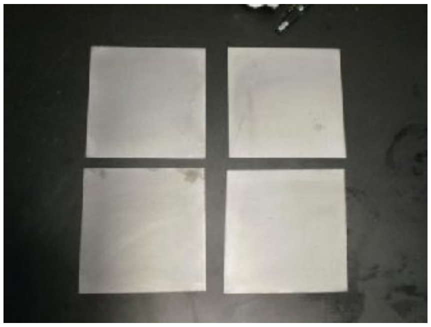
3.1.2.1 SURFACE PREPARATION USING SOLVENT CLEANING

[*Surface Preparation*, www.wilckens-baltic.com/, Retrieved August 23, 2009, 3.30pm]:

The following initial surface preparation is to be applied to steel plates.

1. Oil and grease shall be removed by wiping or scrubbing the steel with clean rags or brushes wetted in solvent, as outlined by the STEEL STRUCTURES PAINTING COUNCIL – SURFACE PREPARATIONS SPECIFICATIONS, SP-1-63: **"SOLVENT CLEANING"**. Deposits firmly adhering to the steel shall first be removed by scrapping and shall than be cleaned using solvent. Refer to Table 3.1 for the material's surface condition before and after using solvent cleaning.

Table 3.1: Comparison before and after Solvent Cleaning

Material	Before Solvent Cleaning	After Solvent Cleaning
Carbon Steel		

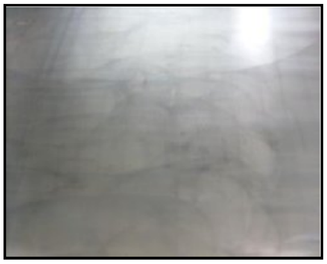
3.1.2.2 SURFACE PREPARATION USING HAND AND POWER TOOL CLEANING [*Surface Preparation*, www.wilckens-baltic.com/, Retrieved August 23, 2009, 3.30pm]:

Defective areas with damage and rust owing to gas cutting, welding, and stress relieving measures must be cleaned by blasting or with power tool cleaning. Degreasing and washing may also be necessary to clean the surface before the subsequent coats are applied. To do so, follows the steps below:

1. Remove corroding salts, chalk marks, soil or other contaminants and foreign matter by brushing the steel with a stiff fibre or wire brush or a combination of both.
2. Deposited oil and grease must be removed using solvent.
3. Use a power tool to clean rust and damaged paint film from areas suffering from stress relief, heat treatment applied to meet Swedish Standard SIS 05 5900 C ST 3.0 as outlined by the STEEL STRUCTURES PAINTING COUNCIL – SURFACE PREPARATION SPECIFICATION SP 3-63: **"POWER TOOL CLEANING"**. When using power tools to clean, use powder sanders and/or power grinders.
4. Use a blast cleaner or power tool to remove weld flux slugs, weld metal spatters, weld flux fume deposits, rust and damaged pain film in welded areas.
5. Use vacuum cleaner to remove dust, sand residue, and other contaminants. Table 3.2 shows the surface preparation by using hand and power tool cleaning.

Please refer to **Appendix 3-1** for Proper Surface Preparation for Steel and **Appendix 3-2** for Surface Preparation; Hand and Power Tool Cleaning.

Table 3.2: Surface preparation using hand and power tool cleaning

Process	**Description**
	1. The operator uses a grinder (***Wire Brush***) which is followed the standard Hand and Power Tool Cleaning -St 3
	2. The result after run uses the hand and power tool cleaning – St 3: ***Very Thorough***.

3.2 EXPERIMENTAL PROCEDURE

3.2.1 WEIGHT THE SAMPLE

The weight of the samples must be measured before and after the sample is coated. A total of eight samples are measured; four for the first type of surface preparation which is using solvent cleaning (SP 1) and another four for the second type of surface preparation which is hand and power tool cleaning (St 3). Figure 3.2 shows the weight of the sample being measured by using the digital weight scale.

Figure 3.2: Specimens calibration before/after coating

3.2.2 SURFACE MEASUREMENT BY SURFACE PROFILER MACHINE

The sample's surface must be inspected by surface profiler machine before and after the sample is coated. The purpose of the inspection is to evaluate the variation of the sample's surface condition before and after the coating is applied. The sample's surface is also inspected before and after the surface preparation. This is to compare if there are any differences on the sample's surface roughness; Ra before and after the surface preparation. Figure 3.3 shows the sample's surface being measured by the surface roughness machine.

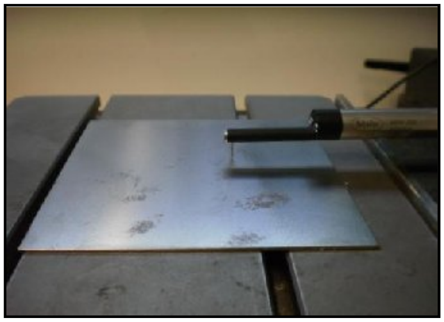


Figure 3.3: Measure the surface roughness; Ra using the surface profiler machine (Before/after Coating)

3.2.3 SAMPLE COATING PROCESS

The next step in the experimental procedure is the sample coating process. The material is coated with a thickness 1.0mm of polyurea. The sample coating is done by Dyna Segmen (M) Sdn Bhd. Figure 3.4 shows the coating process conducted by Dyna Segmen (M) Sdn Bhd.

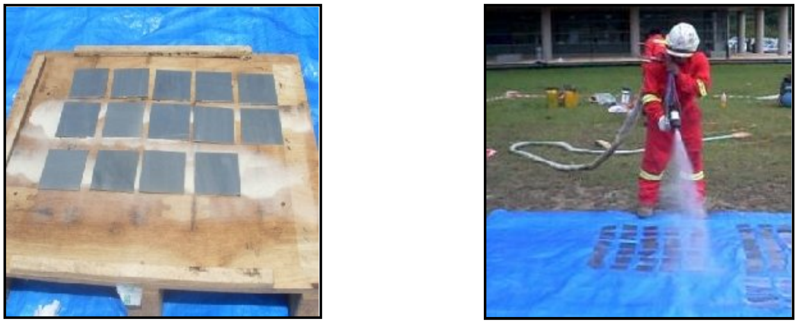


Figure 3.4: Coating process by Dyna Segmen (M) Sdn Bhd

3.2.4 ABRASION TEST ON THE SAMPLE BY USING TABER ABRASER

Abrasion test are conducted on all the samples by using Taber Abraser Machine. The load and cycle used are 1000g and 1000 cycles respectively. Figure 3.5 shows the process for the test sample that undergone with 1000 cycles.

Figure 3.5: Rotary Taber Abraser Machine

Resilient calibrase wheels no. CS-10 as shown in Figure 3.6; is used [2001, *Annual Book of ASTM Standards*, *Section 6*]. CS-10 is a medium abrasive wheel, designed to simulate the abrading action like that of normal handling, cleaning, and polishing. Used to evaluate resistance of wear on materials such as coatings, plastics, textiles, leather and paper products [*Materials Test and Measurement, Taber Abraser; Model 5135 and 5155, http://www.taberindustries.com/Products/Abraser/,* Retrieved August 10, 2009 12.15pm].

Figure 3.6: Calibrase CS-10 as per ASTM D4060-95

Vacuum Pick-Up assembly
[*Materials Test and Measurement, Taber Abraser; Model 5135 and 5155, http://www.taberindustries.com/Products/Abraser/,* Retrieved August 10, 2009 12.15pm]:-

1. Consisting of a vacuum unit, a variable transformer suction regulator, a nozzle with bracket attachment, ad a connecting hose with adaptor.

3.2.4.1 ABRASION TEST PROCEDURE

Standardizations [2001, *Annual Book of ASTM Standards*, *Section 6*]**:-**

a. Mount the selected abrasive wheels on their respective flange holders, taking care not to handle them by their abrasive surfaces. Adjust the load on the wheels (1000g).

b. Mount the resurfacing CS-10 on the turntable. Lower the abrading heads carefully until the wheels rest squarely on the abrasive disk. Place the vacuum pick-up nozzle in position.

c. Set the counter to "zero" and set the suction regulator (approximately 50 points on the dial). The setting may be increased to 90 if more effective removal on the abradings appears necessary.

d. Start the vacuum pick-up and then the turntable of the abrader. Resurface the wheels by running them 1000 cycles against the resurfacing mild-medium.

Test Procedure [2001, *Annual Book of ASTM Standards*, *Section 6*]**:-**

1. Weight the test specimen to the nearest 0.1 mg and record this weight, if either the wear index or the weight loss is to be reported.
2. Measure the specimen before coatings and also after coatings to analyze the coating thickness of the test specimen in several locations along the path to be abraded.
3. Mount the test specimen on the turntable. Place the abrading heads on the test film and the vacuum pick-up nozzle on the positions as outlined in 2. Set the counter and suction regulator as outlined in 3.
4. Start the vacuum pick-up and then the turntable of the abrader. Subject the test specimen to abrasion for the specified number of cycles or until wear through of the coating is observed. In determining the point of wear through, stop the instrument at intervals for examination of the test specimen.

5. Remove any loose abradings remaining on the test specimen by light brushing. Reweight the test specimen and also measure the variety of surface thickness.
6. Repeat step 1 to 5 on the remaining test samples.

3.3 ANALYZE THE EXPERIMENT

3.3.1 *Wear Index, I* – Compute wear index, *I*, of the test specimen:-

$$I = \frac{(A - B)\,1000}{C} \quad \cdots\cdots\cdots\cdots\blacktriangleright \quad \textbf{Eq. 1}$$

Whereby:

A = weight of the test specimen before abrasion (after coating), mg,

B = weight of the specimen after abrasion, mg, and

C = number of cycles of abrasion recorded, 1000 cycles.

3.3.2 *Weight Loss, L* – Compute weight loss, *L*, of the test specimen:-

$$L = A - B \quad \cdots\cdots\cdots\cdots\blacktriangleright \quad \textbf{Eq. 2}$$

Whereby:

A = weight of the test specimen before abrasion (after coating), mg,

B = weight of the specimen after abrasion, mg, and

3.3.3 ***Wear Cycles per Mil, W*** – Compute the wear cycles per mil, W, of the test specimen:-

$$W = D/T \quad \cdots\cdots\cdots\cdots\blacktriangleright \quad \textbf{Eq. 3}$$

Where:

D = number of cycles of abrasion required to wear coating through to substrate and,

T = thickness of coating, mils (0.03937 in.) (to one decimal place).

Please refer to **Appendix 4-2** for Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser.

3.3.4 ***Surface Roughness:*** Measure the surface thickness (t) for each of the specimens and compare it with the 2 different types of the surface preparation i) fine, ii) medium before and after experiment by using the Surface Profiler machine.

3.3.5 ***Surface Thickness:*** Use dry coating thickness gauge as shown in Figure 3.7 to measure the thickness of the coating plate – after coating process.

Figure 3.7: Dry Coating Thickness

3.3.6 ***Surface Profiles Assessment***: Compare with the standard use and Hand and Power Tool Cleaning (St 3) and Solvent Cleaning (ST 1).

3.3.7 ***Surface Analysis by using Scanning Electron Microscope (SEM)***: Lastly, the sample's surface is analyzed under Scanning Electron Microscope. Figure 3.8 shows the Scanning Electron Microscope.

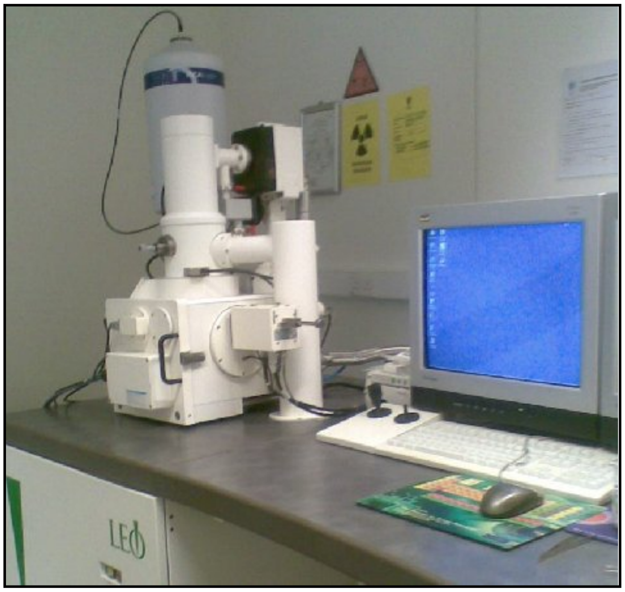


Figure 3.8: Scanning Electron Microscope

3.4 FLOW CHART:

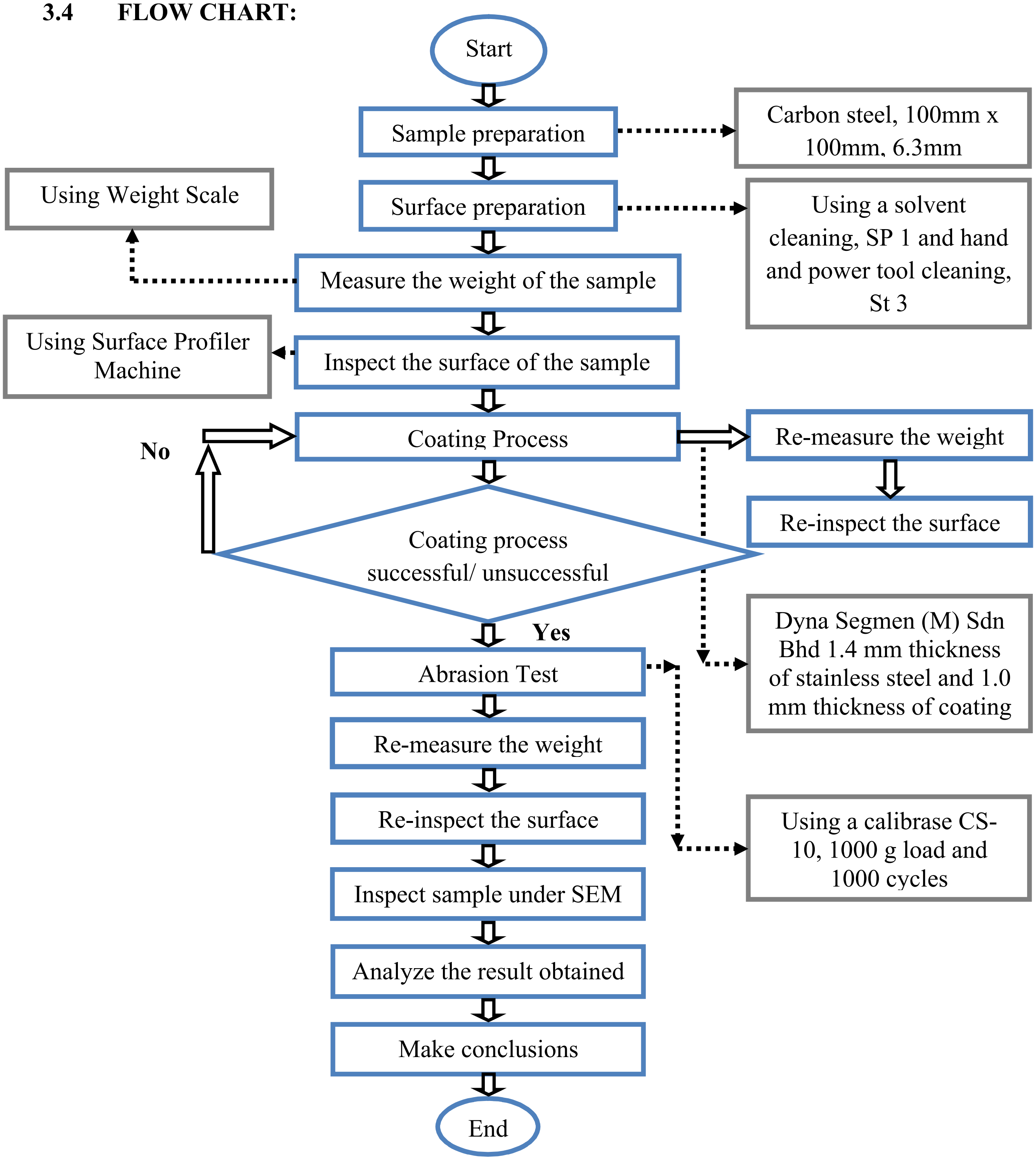


Figure 3.9: Process Flow Chart

Please see **Appendix 3-3** and **Appendix 3-4** for FYP I and FYP II's Gantt Charts

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Data Gathering and Analysis:

4.1.1 Weight of the test samples before and after Surface Preparation:-

Table 4.1: Weight of the test samples before and after Surface Preparation – Solvent Cleaning

Sample No.	Weight before Surface Preparation (mg)	Weight After Surface Preparation (mg)
1	88.08	86.8
2	87.07	86.33
3	87.38	86.58
4	88.16	86.32
Average	88.21	86.51
Standard Deviation	0.53	0.23

Table 4.2: Weight of the test samples before and after Surface Preparation – Hand and Power Tool Cleaning

Sample No.	Weight before Surface Preparation (mg)	Weight After Surface Preparation (mg)
1	88.09	79.05
2	87.64	78.31
3	87.32	79.61
4	88.16	79.09
Average	87.80	79.02
Standard Deviation	0.40	0.53

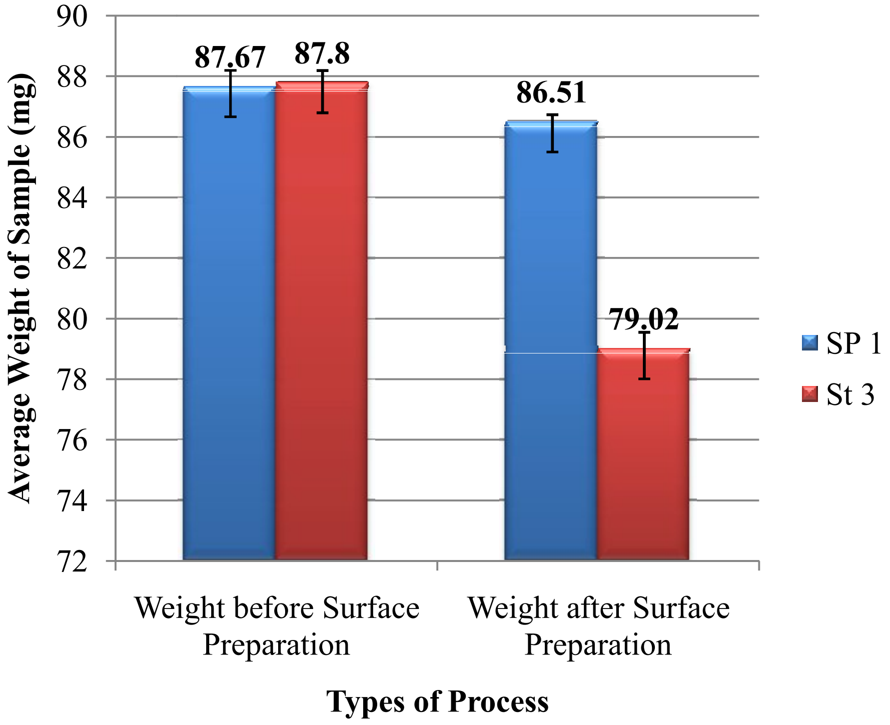


Figure 4.1: Average weight of Test Samples before and after Surface Preparation

Table 4.1 and table 4.2 shows the weight of the test samples according to the types of surface preparation before and after the surface preparation itself. There are two types of surface preparation used which is by Solvent Cleaning; SP 1 and by Hand and Power Tool Cleaning; St 3. The average weight of the test sample used for SP 1 and St 3 before the surface preparation is 87.67mg and 87.8mg respectively, while the average weight of test sample for SP 1 and St 3 after the surface preparation is done is 86.51mg and 79.02mg respectively. By referring to Figure 4.1, it can be clearly seen that the average weight loss on the test samples using St 3 type of surface preparation is larger compared to the average weight loss on the test samples using SP 1 type of surface preparation. The standard deviation of SP 1 sample's weight before and after the surface preparation is 0.53 and 0.23 respectively. The standard deviation of St 3 sample's weight is 0.40 before the surface preparation and 0.53 after the surface preparation. It is observed that the standard deviation of SP 1 sample's weight is reduced after the surface preparation. On the other hand, the standard deviation of St 3 sample's weight is increased after the surface preparation. By using St 3 type of surface preparation, which is by using Hand

and Power Tool cleaning, manual cleaning is performed using hand wire brushes or mechanically operated tools such as grinders or chippers in accordance with ISO 8501-1, refer to **Appendix 2-1** for Surface Preparation as per PETRONAS Technical Standard (PTS). Then the surface is left roughly abraded in accordance with SSPC-SP11; Power Tool Cleaning to Bare Metal. As the sample surfaces are cleaned by using power tool or mechanically operated tool, the tool not only clean the sample's surface, but simultaneously it also removes a layer from the sample's surface as a result of cleaning action. Which is why, the average weight loss by using St 3 type of surface preparation is higher compared SP 1. As by using SP 1 type of surface preparation, which is by using Solvent Cleaning, surface contaminants such as oil, grease, hydrocarbon, etc is removed in accordance of SSPC-SP 1; Solvent Cleaning. The degreased surface is then further washed with fresh water to remove all traces of the degreaser chemicals. The surface is then allowed to dry thoroughly before proceeding with any further coating work. This type of surface preparation only moves unwanted particles or debris from the sample's surface, thus, the average weight loss by using this kind of surface preparation is quite small.

4.1.2 Weight of the test samples before and after abrasion test with Taber Abraser:-

Table 4.3: Weight after coating, before and after abrasion test (mg) - Solvent Cleaning (SP 1)

Sample No.	Weight before Abrasion Test (mg)	Weight After Abrasion Test (mg)
1	102.45	101.63
2	103.12	102.71
3	102.34	101.97
4	103.56	103.28
Average	102.87	102.4
Standard Deviation	0.58	0.74

Table 4.4: Weight after coating, before and after abrasion test (mg) - Hand and Power Tool Cleaning (St 3)

Sample No.	Weight before Abrasion Test (mg)	Weight After Abrasion Test (mg)
1	115.12	114.75
2	116.11	115.99
3	116.06	116.06
4	106.43	106.35
Average	113.43	113.29
Standard Deviation	4.69	4.66

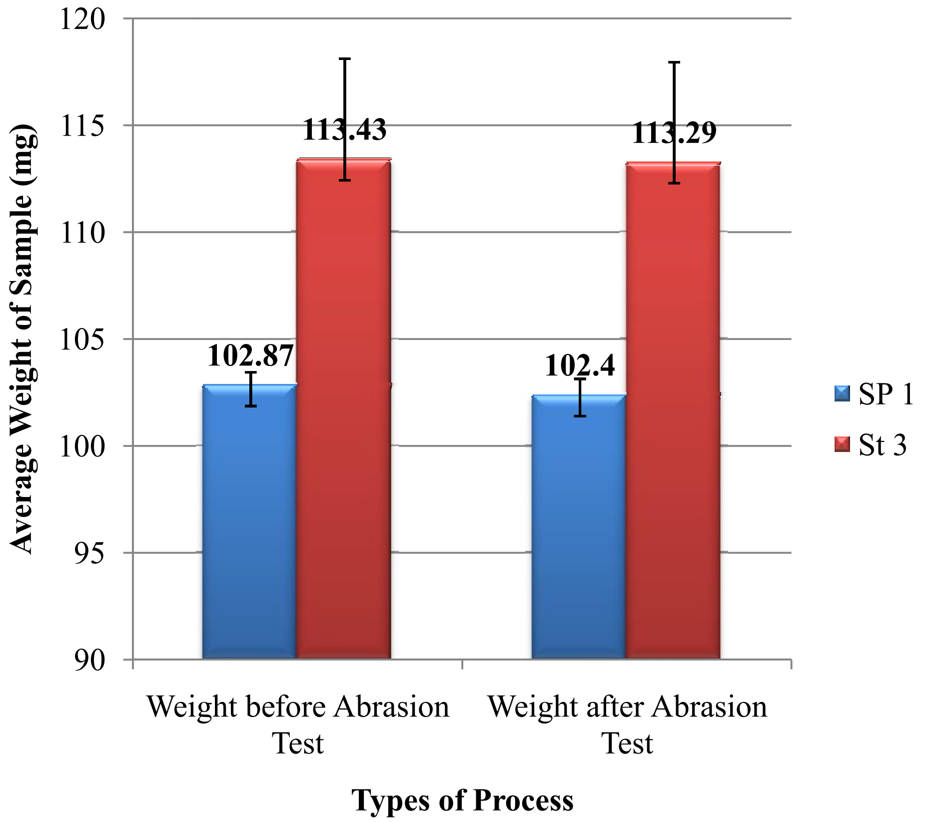


Figure 4.2: Average weight of Test Samples with Different Surface Preparation before and after Abrasion Test

Figure 4.3: Test Sample after Polyurea Coating Process

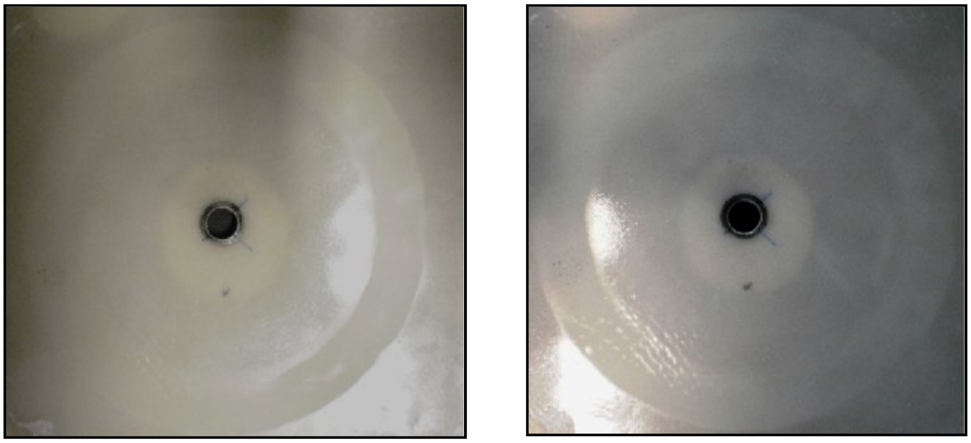


Figure 4.4: A Test Sample after run With the Taber Abraser Machine

Table 4.3 and Table 4.4 shows the weight after coating before and after abrasion test (mg) for two type of surface preparation which is Solvent Cleaning; (SP 1) and Hand and Power Tool Cleaning; (St 3). From the Graph constructed in Figure 4.2, the difference of the test samples weight for both type of surface preparation before and after abrasion test can be clearly seen. The average weight for both samples is reduced after the abrasion test. The average weight of test sample for SP 1 is 102.87mg before the abrasion test and 102.4mg after the abrasion test, while the average weight of test sample for St 3 is 113.43mg before the abrasion test and 113.29mg after the abrasion test. The reduction of weight on both types of samples indicates that the abrasive test had caused some material loss from the test samples. Other than that, it is observed that the standard deviation of the test sample's weight by using SP 1 as surface preparation is 0.58 before the coating process and 0.74 after the coating process. The standard deviation value increased after the coating process. Whereas the standard deviation of the test sample's weight by using St 3 as surface preparation is 4.69 before the coating process and 4.66 after the coating process, which shows some reduction in standard deviation. The standard deviation for SP 1 sample's weight show a large increment before and after the coating process while the standard deviation for the St 3 sample's weight show a small reduction before and after the coating process. This is due to the interlocking bond between the polyurea coating and the metal surfaces. St 3 type of surface preparation results in strong mechanical bond between the metal surface and the polyurea coating, thus reduce the material loss from the test sample. On the other hand, SP 1 did not provide mechanical bond as strong as St 3, thus, the amount of material loss is bigger. This denote that St 3 surface preparation technique increase the abrasion wear resistance of the polyurea coating. Figure 4.3 and 4.4 shows test sample after coating and after run with the Taber Abraser Machine.

4.1.3 Wear Index of the test samples:-

Table 4.5: Wear Index, *I*, for group sample of Solvent Cleaning (SP 1)

Sample No.	Wear Index (mg/cycles)
1	0.82
2	0.41
3	0.36
4	0.28
Average	0.47
Standard Deviation	0.24

Table 4.6: Wear Index, *I*, for group sample of Hand and Power Tool Cleaning (St 3)

Sample No.	Wear Index (mg/cycles)
1	0.36
2	0.12
3	-
4	0.08
Average	0.19
Standard Deviation	0.15

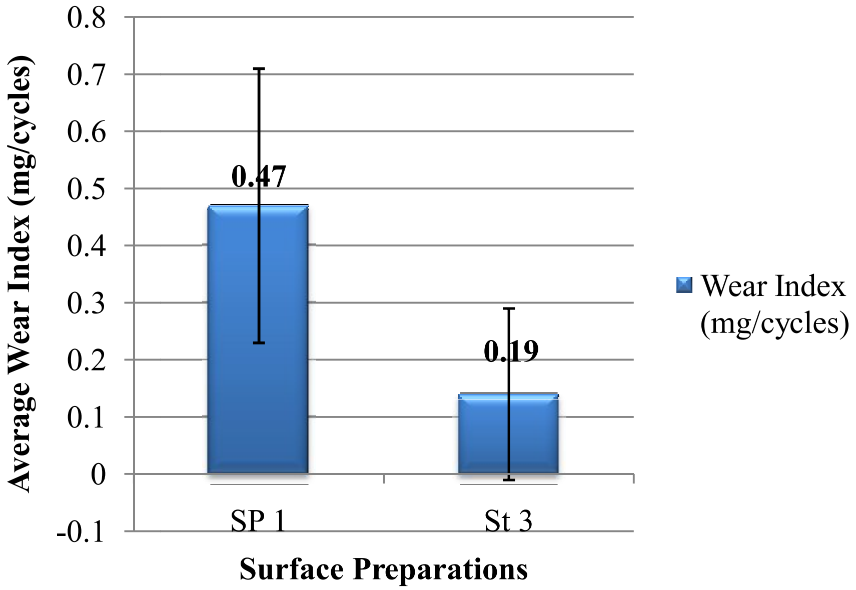


Figure 4.5: Average Wear Index of Test Samples with Different Surface Preparation

Table 4.5 shows the Wear Index, I for test samples using Solvent Cleaning surface preparation; SP 1, while Table 4.6 shows the Wear Index, I for test samples using Hand and Power Tool Cleaning surface preparation respectively. The average Wear Index, I of test samples using SP 1 is 0.47mg/cycles and the average Wear Index, I of test samples using St 3 is 0.19mg/cycles respectively. Figure 4.5 shows the comparison of Wear Index, I of test samples with different surface preparation. In terms of standard deviation, the wear index of the test sample for SP 1 type of surface preparation has standard deviation of 0.24 while the test sample for St 3 type of surface preparation has standard deviation of 0.15. SP 1's test sample has higher standard deviation value compared to St 3's test sample. Test sample no 3 for St 3 type of surface preparation has no wear index value due to some human error which occurred during the coating process. Lower wear index is desired as wear index actually indicates the weight loss per cycle of the test samples. The lower the value of the wear index obtained means the smaller the weight loss per cycle of the material is. In this case, the weight loss per cycles is larger for the test sample using SP 1 compared to the weight loss per cycles for test sample using St 3. The low wear index value obtained for St 3 test sample is due to the interlocking bond between the polyurea coating and the metal surfaces as a result of successful surface preparation. St 3 type of surface preparation results in the rough surface of the sample which contributes in the bonding process. The sample's rough surface provides better grip to the polyurea coating which effects in better bonding between two materials.

4.1.4 Weight Loss of the test samples:-

Table 4.7: Weight Loss, *L*, for group sample of Solvent Cleaning (SP 1)

Sample No.	Weight Loss (mg)
1	0.82
2	0.41
3	0.36
4	0.28
Average	0.47
Standard Deviation	0.24

Table 4.8: Weight Loss, *L*, for group sample of Hand and Power Tool Cleaning (St 3)

Sample No.	Weight Loss (mg)
1	0.36
2	0.12
3	-
4	0.08
Average	0.19
Standard Deviation	0.15

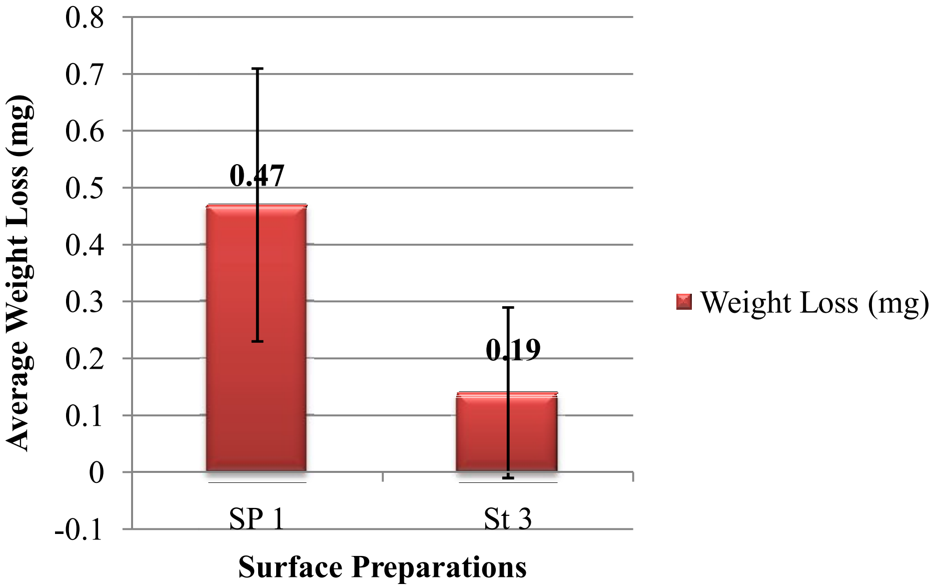


Figure 4.6: Average Weight of Test Samples with Different Surface Preparation

Table 4.7 and table 4.8 shows the Weight Loss, L of the test sample by using SP 1; Solvent Cleaning types of surface preparation and St 3; Hand and Power Tool Cleaning respectively. From table 4.7, the average weight loss of SP 1 test samples is 0.47mg. While the average weight loss of St 3 tests samples is 0.19mg according to table 4.8. As shown in Figure 4.6; Average Weight of Test Samples with Different Surface Preparation, the average weight loss on SP 1's test samples is larger compared to the average weight loss on St 3's test samples. The standard deviation of the average weight loss of SP 1's test samples is 0.24 which is higher compared to the standard deviation of the average loss of St 3's test samples which is only 0.15. Test sample number 3 for St 3 type of surface preparation has no weight loss value due to some error occurred to the test sample during the coating process. St 3's test samples only experience small weight loss compared to SP 1 test samples. By relating the average weight loss results with the wear index obtained, it is proved that the bigger the value of the wear index, the larger the amount of the weight loss of the test samples. This imply that surface preparation is important in polyurea coating as it will effects the abrasion wear resistance of the polyurea coating itself.

4.1.5 Wear Cycle per Mil of the test samples:-

$$\boldsymbol{W = D / T} \qquad \cdots\cdots\cdots\cdots\blacktriangleright \quad \textbf{Eq. 3}$$

$$= \frac{1000 \text{ cycles}}{0.03937 \text{ in.}}$$

$$= 25400051 \text{ wear cycles/mils}$$

Wear Cycle per Mil is the number of cycles of abrasion required to wear a film through to the substrate per mil of film thickness. The thickness of polyurea coating used for this experiment is 0.03937 in. By using 1000 cycles, 25400051 wear cycles/mils is required to wear the coating through to the substrate which in this case is carbon steel.

4.2 Test Sample Surface Roughness – Average Roughness, Ra

4.2.1 Surface Roughness, of the samples for the different surface preparation:-

Surface roughness of the steel plate ***after run with the taber abrader***:

i. Solvent Cleaning (SP 1)

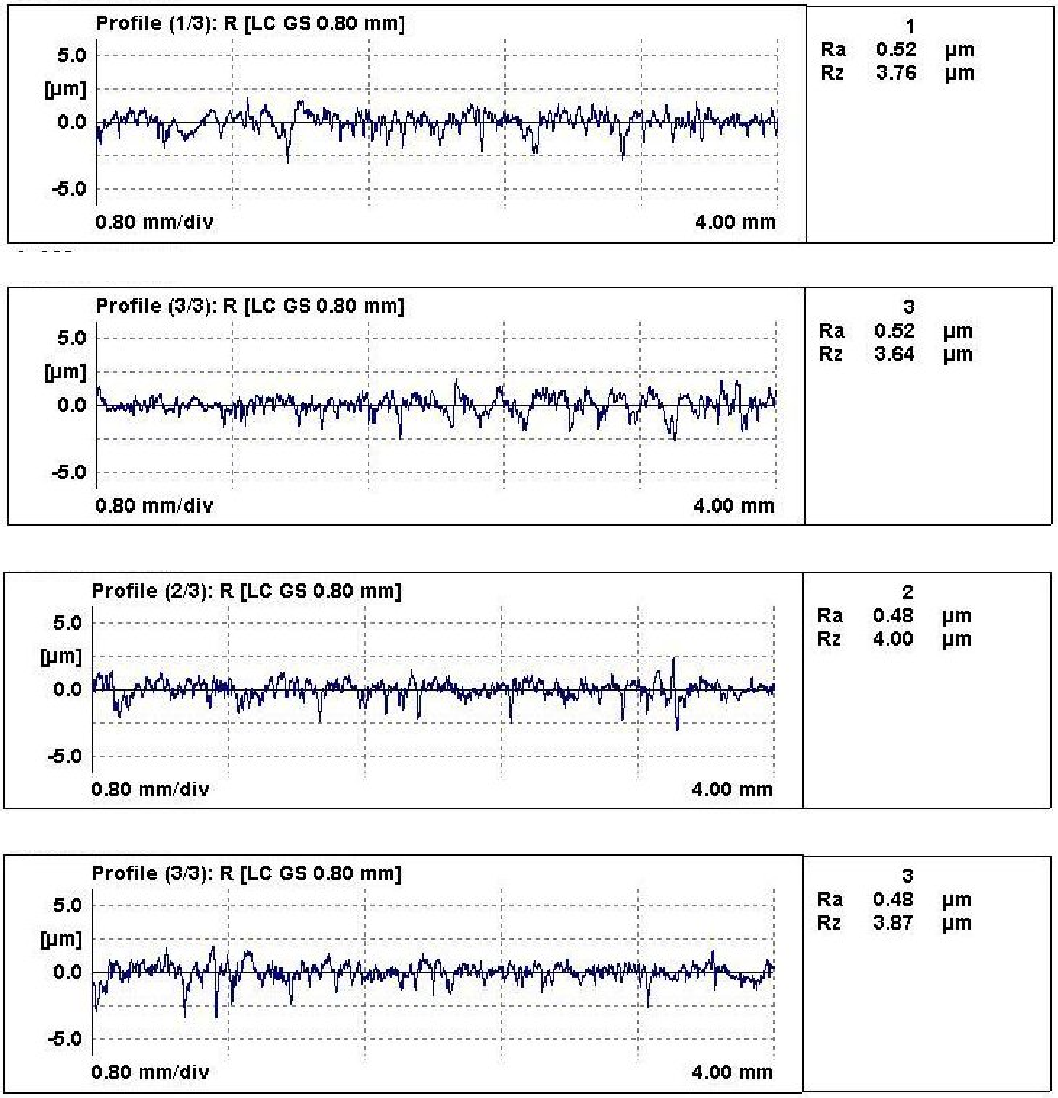


Figure 4.7: Comparison between 4 measurements – Solvent Cleaning (SP 1)

ii. Hand and Power Tool Cleaning (St 3)

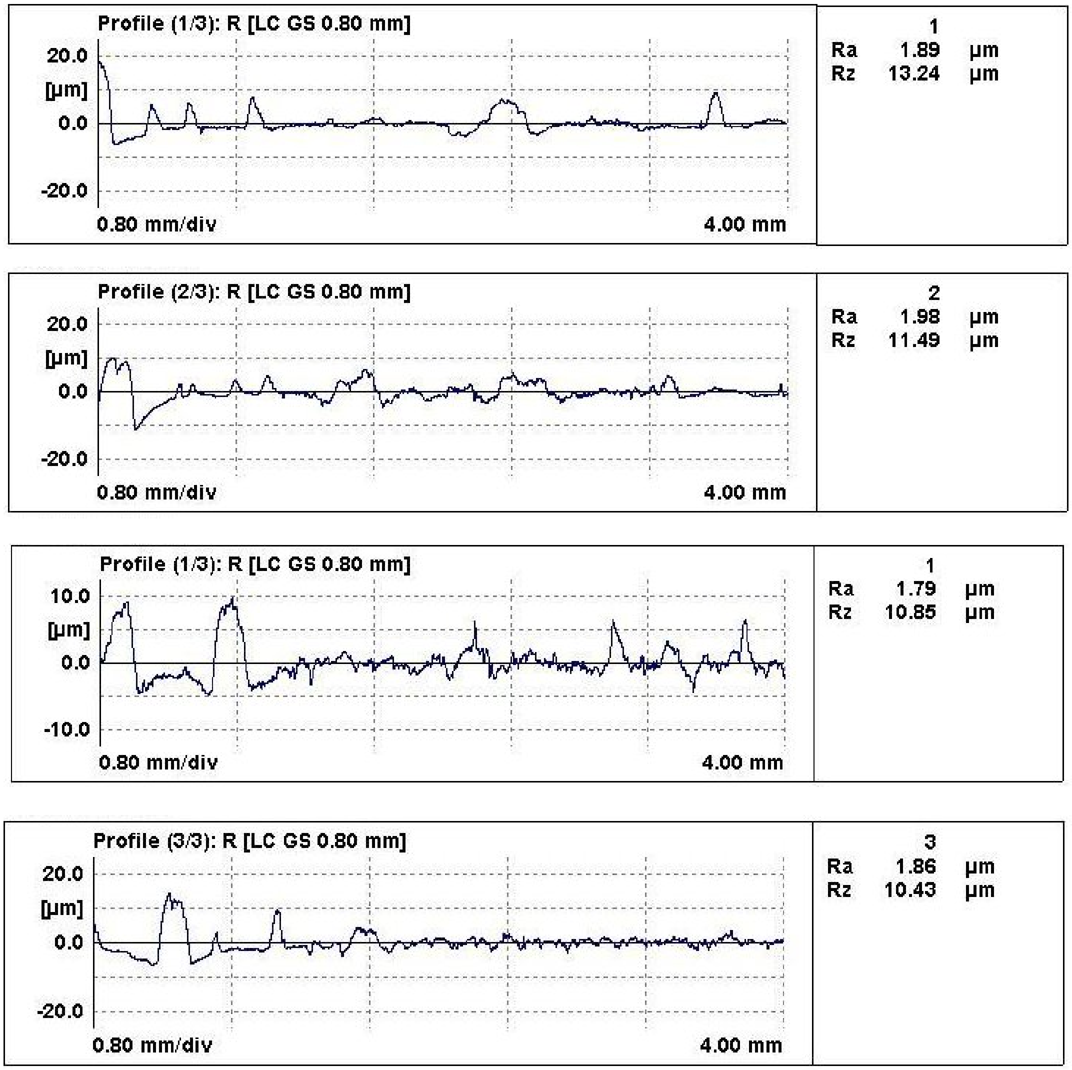


Figure 4.8: Comparison between 4 measurements – Hand and Power Tool Cleaning (St 3)

Please refer to **Appendix 4-1** for further Data from Surface Profiler Machines.

Table 4.9: Average Roughness, Ra for group sample of Solvent Cleaning after Surface Preparation

Sample No.	Ra (μm)
1	0.93
2	0.85
3	0.97
4	0.88
Average	0.91
Standard Deviation	0.05

Table 4.10: Average Roughness, Ra for group sample of Hand and Power Tool Cleaning after Surface Preparation

Sample No.	Ra (μm)
1	1.05
2	1.03
3	1.05
4	1.01
Average	1.04
Standard Deviation	0.02

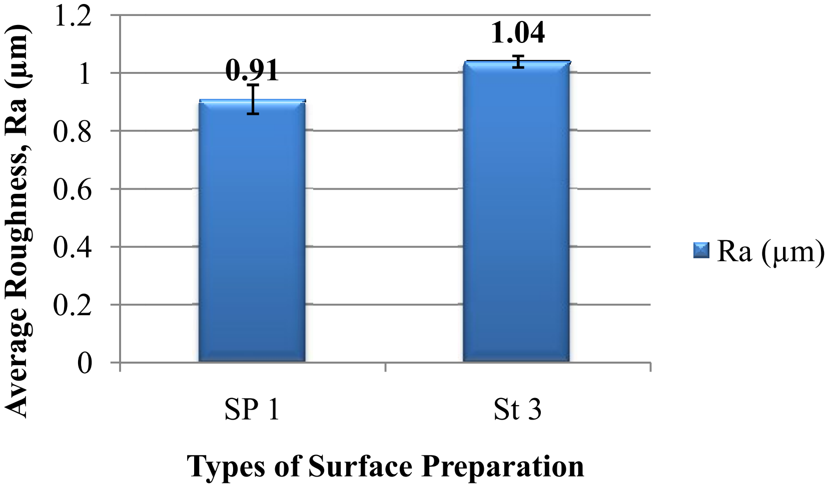


Figure 4.9: Average Roughness, Ra of Test Samples after Surface Preparation

Average Roughness; Ra, is one of the most effective surfaces roughness measures used in engineering practice It gives general description of the height variations in the surface. Table 4.9 shows the average roughness of the test samples using SP 1 surface preparation while Table 4.10 shows the average roughness of the test samples using St 3 surface preparation. The average roughness of SP 1 test samples is 0.91µm as stated in table 4.9 and the average roughness of St 3 test samples is 1.04µm as stated in table 4.10. The comparison of average roughness between SP 1 test samples and St 3 test samples can be observed in Figure 4.9; Average Roughness of Test Samples after Surface Preparation. The standard deviation for the average roughness of St 3 test samples is 0.05 compared to the standard deviation for the average roughness of SP 1 test samples which has a lower value that is 0.02. The high value of average roughness obtained by St 3 test samples is the effect of the surface preparation by using Hand and Power Tool. Hand and Power Tool surface preparation caused the surface of the test sample rougher than the original condition as preparation to the sample before the coating process. SP 1 type of surface preparation is by using Solvent Cleaning to wipe and polish the test sample's surface and removes undesired surface contaminants thus, leaving the test sample's surface clean. The difference is that, Solvent Cleaner did not cause the surface as rough as the test sample's surface which used hand and power tool.

Table 4.11: Average Roughness, Ra for group sample of Solvent Cleaning after Coating

Sample No.	Ra (µm)
1	2.05
2	2.02
3	1.14
4	1.88
Average	1.77
Standard Deviation	0.43

Table 4.12: Average Roughness, Ra for group sample of Hand and Power Tool Cleaning after Coating

Sample No.	Ra (µm)
1	3.33
2	3.32
3	5.85
4	3.52
Average	4.01
Standard Deviation	1.23

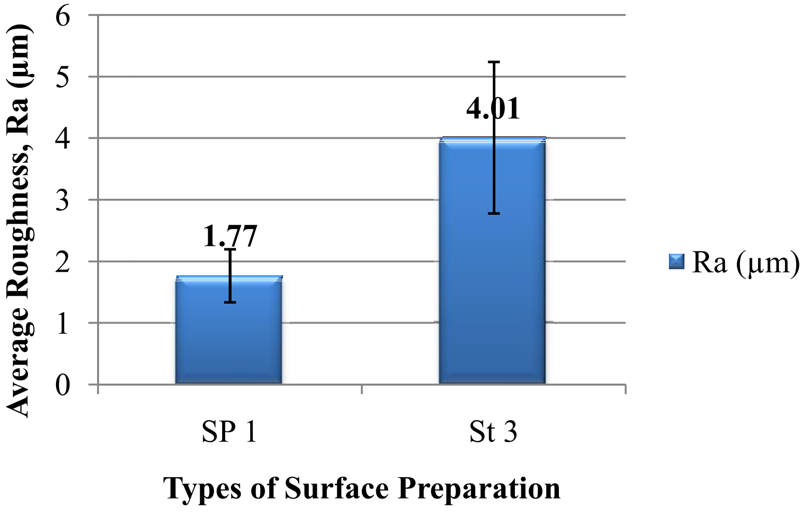


Figure 4.10: Average Roughness, Ra of Test Samples with Different Surface Preparation after Coating

Table 4.11 and Table 4.12 shows the average roughness of the test samples for both type of surface preparation which is Solvent Cleaning; SP 1, and Hand and Power Tool Cleaning; St 3 after coating. From both tables, the average roughness of SP 1's test samples is 1.77µm and the average roughness of St 3's test samples is 4.01µm. Figure 4.10 illustrates the average roughness of the test samples with different type of surface preparations after coating process. The standard deviation of average roughness for SP 1's test sample after the coating process is 0.43 and the standard deviation of average roughness for St 3's test sample after the coating process is 1.23. It is noticed that standard deviation of St 3's test sample is higher than SP 1's test sample. The reason of SP 1 test samples having a lower average roughness value compared to St 3 test sample is the surface preparation undergone by the test samples before the coating process. Both SP 1 and St 3 surface preparation method is done to clean the test sample's surface so that the coating process successful. The dissimilarity is that St 3 method causes the surface to become rougher compared to SP 1 method. As the metal has rough surface, the coating applied which has already bond well with the surface, also follows the roughness of the metal surface. This is why the test sample which has been coated also has high average roughness. SP 1 method on the other hand, did not cause the metal's surface to become rougher as much as St 3 method does. Thus, the coating applied which also follows the metal surface's roughness condition, has lower average roughness value.

Table 4.13: Average Roughness, Ra for group sample of Solvent Cleaning after Abrasion Test

Sample No.	Ra (µm)
1	0.52
2	0.52
3	0.48
4	0.48
Average	0.50
Standard Deviation	0.02

Table 4.14: Average Roughness, Ra for group sample of Hand and Power Tool Cleaning after Abrasion Test

Sample No.	Ra (µm)
1	1.89
2	1.98
3	1.79
4	1.86
Average	1.88
Standard Deviation	0.08

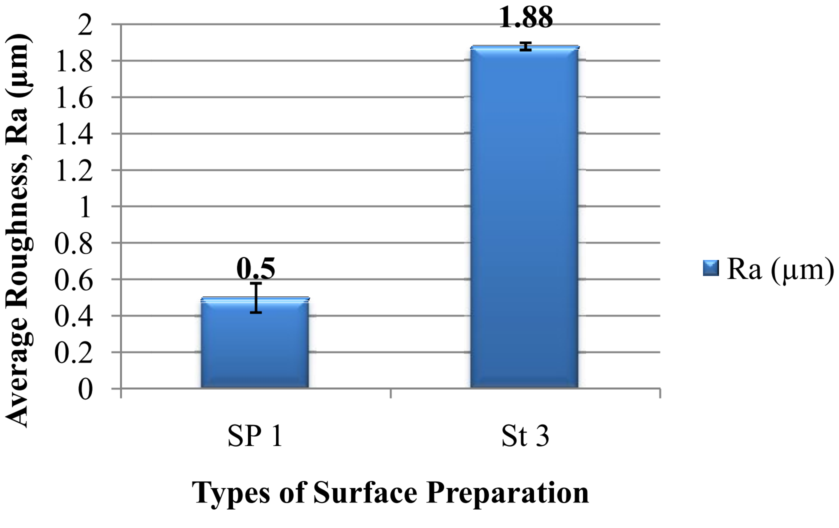


Figure 4.11: Average Roughness, Ra of Test Samples with Different Surface Preparation after Abrasion Test

Table 4.15: Average Roughness, Ra of Test Samples with Different Surface Preparation before and after Abrasion Test

Sample	Before Abrasion Test	After Abrasion Test
SP 1	1.77	0.5
St 3	4.01	1.88

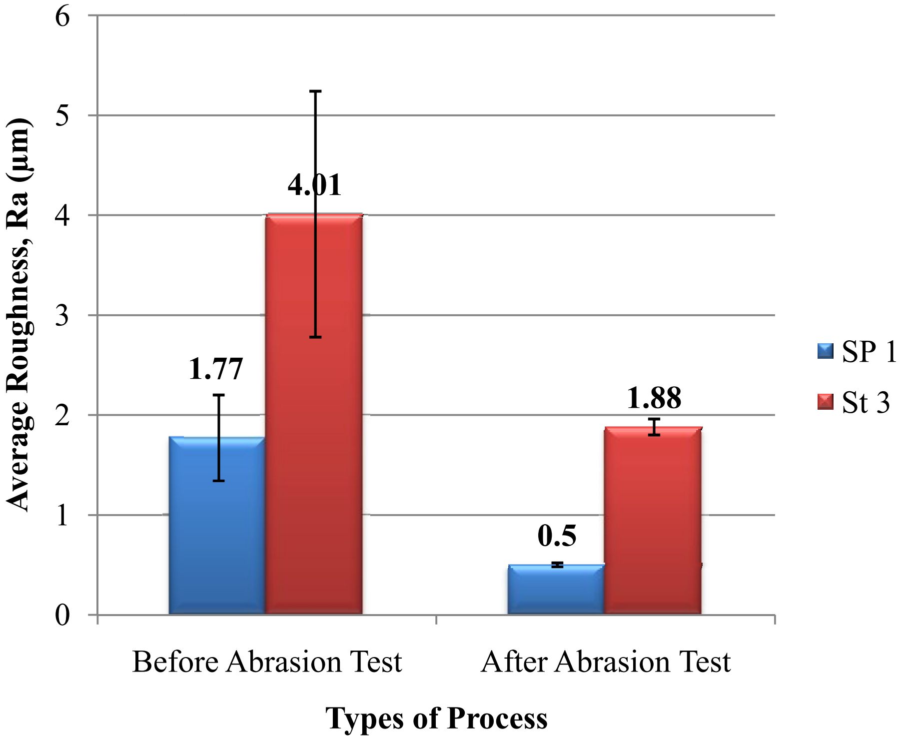


Figure 4.12: Average Roughness, Ra of Test Samples with Different Surface Preparation before and after Abrasion Test

The abrasion test has been conducted on both type of test samples. The test is run with 1000 cycles on each test sample. Table 4.15 shows the average roughness of test samples with different surface preparation before and after the abrasion test. Figure 4.12 illustrates the average roughness of test samples with different surface preparation before and after abrasion test. As shown in the figure, St 3's test sample shows high value of average roughness before and after the abrasion test with value of 4.01µm and 1.88µm respectively. SP 1's test sample shows low average roughness value before and after abrasion test with value of 1.77µm and 0.5µm respectively. It can be seen that even after the abrasion test, St 3's test sample still has the higher average roughness value compared to SP 1's test sample which has low average roughness value before and after the abrasion test. The standard deviation for the average roughness of SP 1's test sample is only 0.02 after the abrasion test which is quite low compared to the standard deviation for the average roughness of St 3's test sample which is 0.08 after the abrasion test.

4.3 Test Sample surface profile by using Scanning Electron Microscope, (SEM):

4.3.1 Magnification – 150 X

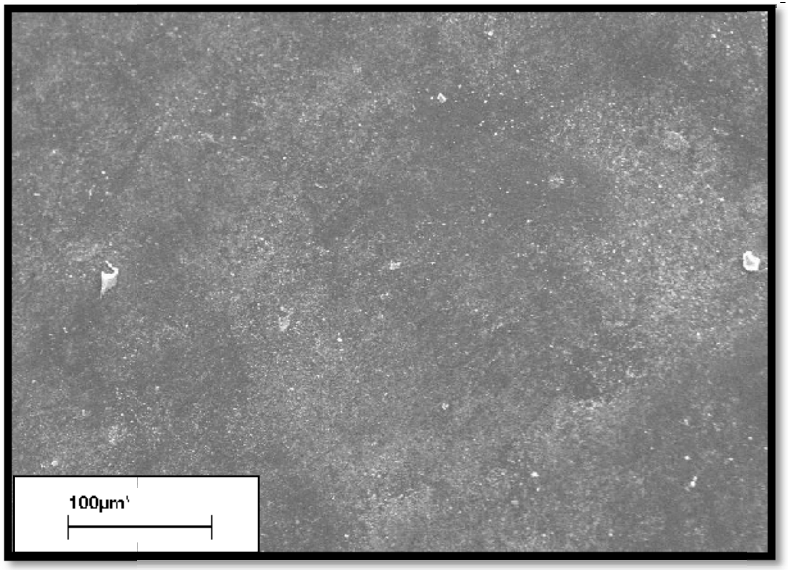


Figure 4.13: Surface morphology of SP 1's test sample after abrasion test with 150x magnification

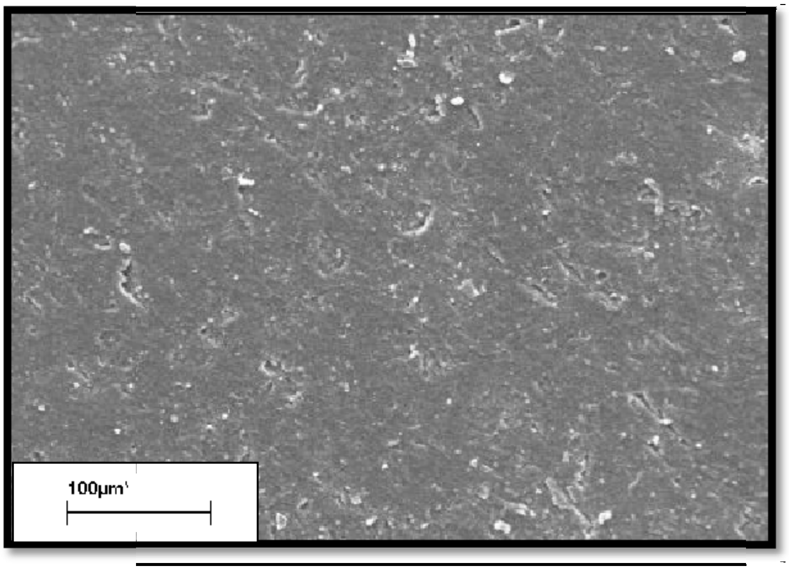


Figure 4.14: Surface morphology of St 3's test sample after abrasion test with 150x magnification

4.3.2 Magnification – 500 X

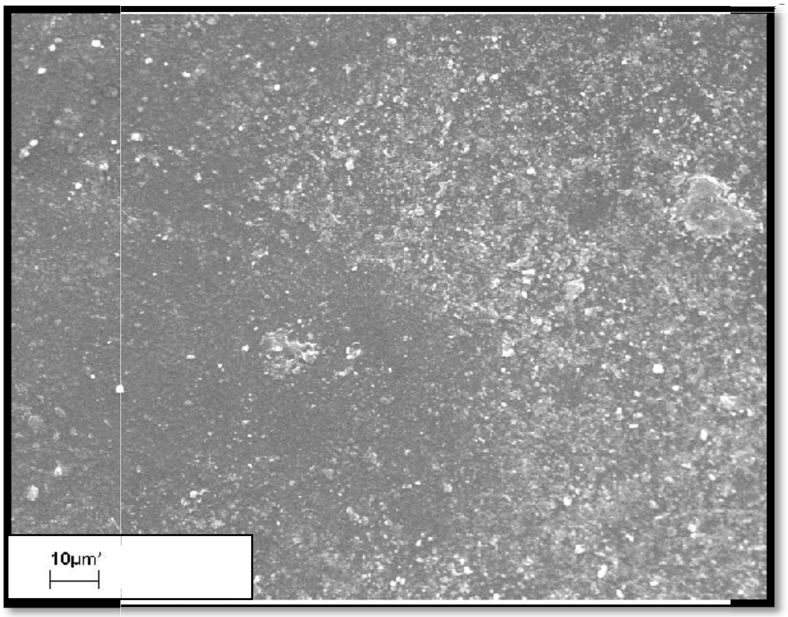


Figure 4.15: Surface morphology SP 1's test sample after abrasion test with 500x magnification

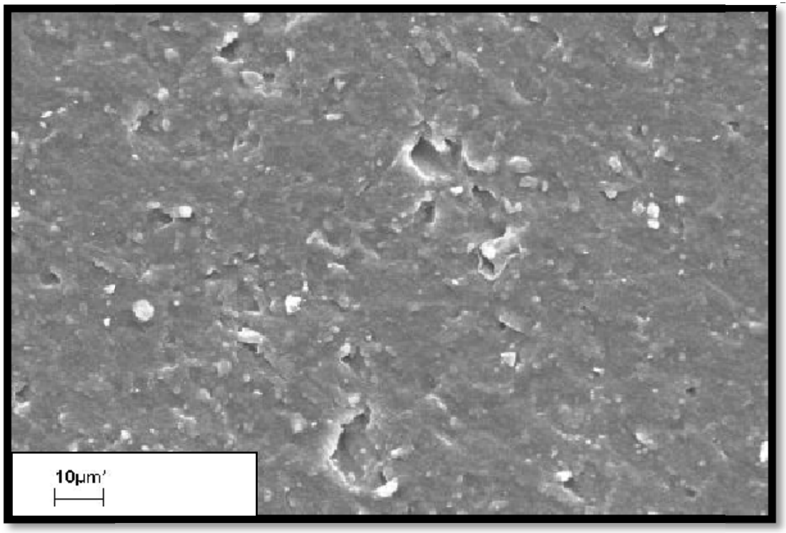


Figure 4.16: Surface morphology St 3's test sample after abrasion test with 500x magnification

Scanning Electron Microscope; SEM is used to analyze the test sample’s surface profile after the abrasion test conducted. Figure 4.13 shows the surface profile of SP 1’s test sample after the abrasion test at 150x magnification, Figure 4.14 shows the surface profile of St 3’s test sample after the abrasion test at 150x magnification, Figure 4.15 shows the surface profile of SP 1’s test sample after the abrasion test at 500x magnification, and last but not least, Figure 4.16 shows the surface profile of St 3’s test sample after the abrasion test at 500x magnification. As shown in the figures, SP 1’s test sample has a smoother surface compared to St 3’s test sample which has a rougher surface. The difference between the surfaces can be clearly seen at 500x magnification. By relating back the surface profile analysis done by SEM with the average roughness; Ra results obtained, it is proven that St 3’s test sample has higher average roughness. By further comparing the analysis with the weight loss obtained for both type of sample, it is also proven that St 3’s test sample which experience smaller weight loss, has exhibit high abrasion wear resistance. Meaning, St 3’s test sample has better ability to withstand material’s removal action from its surface.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From all the results obtained through the experimental process and the analysis conducted, it can be concluded that St 3 surface preparation method, which is by using Hand and Power Tool is more successful in producing coating with low wear index value which is 0.19 mg/cycle compared to SP 1 surface preparation give the high wear index value 0.47 mg/cycle. The lower value of wear index, in this case St 3 indicates that the test sample produce has higher abrasion wear resistance. The small value of wear index means less weight loss per cycle. Hand and Power Tool prepare the steel's surface by not only removing undesired surface contaminant such as oil, greasing and other debris; it also leaves the surface in rough condition to provide traction to the polyurea coating during the coating process. As a result, stronger bond is formed between the carbon steel's surface and the polyurea coating, which then makes the coating stronger and has better ability to abrasion wear resistance. Meaning, the ability of the polyurea coating to withstand mechanical action such as rubbing or scrapping which tends to remove material from its surface is higher. By relating this to real life condition, this type of coating will improve the life of the material which being protected as the material will not wear easily and will not be easily damaged.

Relating back to the objective of this research, both objectives of this research has been achieved successfully. The abrasion wear resistance of the polyurea coating has been determined by using the Taber Abraser machine whereby the polyurea coating exhibit higher abrasion wear resistance with the use of proper surface preparation; in this case Hand and Power Tool cleaning. It is also proven that surface preparation does affect the abrasive wear resistance of the polyurea coating, as different surface preparation affects the metal surface differently. As known, different surface condition or different surface roughness contributes in the bonding strength between the polyurea coating and the steel's surface. Solvent cleaning only cleans the surface by removing all unwanted contaminants from the surface but it did not really change the metal's surface roughness. Hand and Power Tool cleaning cleans the surface and at the same time changing the metal's surface condition by leaving the metal surface rough. Rough surface provides better bonding between the polyurea coating and the metal surface. Therefore, Hand and Power Tool type of surface preparation is better in generating strong bonding between the surfaces thus resulting in polyurea coating with high abrasive wear resistance.

As conclusions, coatings applied using polyurea processes typically depend on a mechanical (interlocking) bond. The nature of the substrate surface is therefore the key to the quality of the coatings. In order to obtain successful coatings, the substrate surface needs to be rough and pitted so that it can provide a "foot-hold" (Splat-Hold) for each splat of powder that impacts the substrate. In addition, the surface needs to be clean and free from contamination that would fill the pits and prevent locking of the splats. Hand and power tool is popular for surface preparations, which is usually conducted using wire brush. The average roughness, Ra of the test sample that use St 3 give the high value which is 1.04 µm after surface preparation and increased up to 4.01 µm after coating. It is indicates that the average roughness by using this St 3 is 4 times up compared to SP 1 which gives the value 0.91 µm after surface preparation and up to 1.77 µm after coating. The depth of the "valley" formed is determined by the size, type and hardiness of the abrasive being used. The rougher the surface indicates that more anchor pattern produced. High number of anchor pattern produced increased the bonding surface between the material and the substrate In this case, by using St 3 types of surface preparation more anchor pattern is produced thus providing better bonding surface.

5.2 RECOMMENDATION

Surface preparation is one of the main important things throughout this project and also one of the objective for this project is to vary the different kind of surface preparation with the surface roughness on polyurea coating in order to make this project more reliable compare it with the current project. The only missing surface preparation in this project is by using the Standard Abrasion, Sa 2.5. This standard abrasion is another type of surface preparation which can be added to improve the result of the experiment. Due to time constraint and unavailability of the machine which up to the standard required for standard abrasive surface preparation in UTP, that type of surface preparation could not be carried out through this project. Therefore for future improvement, it is recommended that this type of surface preparation is added into the research. Through this type of surface preparation, it is hope that more accurate result could be obtained as standard abrasive is the best type of surface preparation.

Conduct pre-test on the substrates in this case carbon steel before it is coated by polyurea. This is to get the reference point (data) to compare with another substrate which is coated with the polyurea.

Another recommendation is to make some variation in the load and cycles used during the abrasion test. Due to time constraint, and limited time access to the machine, the variation in the load and cycles could be done. It is hope that further research is conducted and this time by vary the load and cycles in the abrasion test, the trend exhibited by the polyurea coating will be clearer. Thus, more improvement can be done to the polyurea coating to improve its strength and abrasion wear resistance.

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APPENDIX 2-1

A. **SURFACE PREPARATION as per Petronas Technical Standard (PTS)** [Petronas Technical Standard – Design and Engineering Core, PTS 30.48.00.31 – P, verified on 1999]:

For optimum paint coating performance, surfaces to be painted or coated shall be completely dry and free from burrs, weld spatter, flux, rust, loose scale, dirt, grease, oil and other foreign matter before any paint is applied.

The presence of contaminants is in accordance with procedures described in *ISO 8502-1* and the contaminants removed in accordance with procedures described in NACE Publication prior to blasting or power tool cleaning.

The surface preparation grades shall be specified for the various painting and coating systems also the nearest equivalents of the main surface preparation specifications are given below:

Table 2.1: Types of the surface preparation with the standard

TOOL CLEANING	SSPC	ISO 8501-1	NACE
EXTREMELY THOROUGH.POWER TOOL CLEANING.	SP 11	-	-
VERY THOROUGH. POWER TOOL CLEANING.	SP 3	St 3	-
THOROUGH. HAND TOOL CLEANING.	SP 2	St 2	-
SOLVENT CLEANING	**SSPC**	**ISO**	**NACE**
SOLVENT CLEANING	SP 1	-	-

B. PRE-CLEANING OF SURFACES AND SOLVENT CELANING

[Petronas Technical Standard – Design and Engineering Core, PTS 30.48.00.31 – P, verified on 1999]:

This cleaning procedure is mandatory before further cleaning or surface preparation. Prior to the actual cleaning operation, surface contaminants such as oil, grease, hydrocarbon, etc. shall be removed preferably by degreasing with suitable degreaser or solvent cleaning according to *SSPC-SP1*. The degreased surface shall be further washed with fresh water to remove all traces of the degreaser chemicals. The surface shall be allowed to dry thoroughly before proceeding with any further coating work. *This procedure also applies to all metal surfaces to be coated that do not require blast cleaning or power tool cleaning*.

Before abrasive blast cleaning, all equipment which could not damaged by blast, dust or particulate matter shall be suitably protected by masking, wrapping, tapping, or other means to prevent damage. Where require, the degree of contamination shall be assessed in accordance with procedures described in *ISO 8502-3*. This equipment shall include, but not necessarily be limited to the following:

- Bearings
- Screws
- Exposed moving parts
- Conduit
- Machined surfaces

All edges shall be ground to a minimum radius of 2 mm; flame cut areas shall be ground flush. Offshore maintenance painting projects shall always start with a high pressure steam/detergent to remove dirt and salt deposits. In addition, after a long interval prior to the application of subsequent layers of coating systems, or after a storm the surface shall be steam cleaned before the application of the next layer [Petronas Technical Standard – Design and Engineering Core, PTS 30.48.00.31 – P, verified on 1999].

C. SURFACE PREPARATION BY HAND POWER TOOL CLEANING

CLEANING [Petronas Technical Standard – Design and Engineering Core, PTS 30.48.00.31 – P, verified on 1999]:

The most technically effective surface preparation method is blast-cleaning. Manual preparation shall only be used when blast-cleaning is either not feasible or not strictly required, e.g. galvanized steel, stainless steel.

Manual cleaning shall be performed using hand wire brushes or mechanically operated tools (grinders, chippers or wire brushes) in accordance with *ISO 8504-3*. The surface shall be left roughly abraded to meet the requirement of *SSPC-SP11* and a burnished surface shall be avoided.

Where welds occur within these areas or when these areas cannot accommodate a power disc, power impact tools shall be applied (vibratory and rotary hammers, needle guns, chisels) followed by brush cleaning.

If the surface being prepared lies adjacent to a coated surface which is not to be re-furbished, the power tool cleaning shall overlap the coated surface by *at least 25 mm*. The minimum requirement for successful coating application is *St 3* at the time of coating.

Care shall be taken to ensure that the substrate surface does not become polished during power tool cleaning.

APPENDIX 2-2

Below please note a table for the Surface Preparation Standards generally used in the marine and other industries [*SSPC Description and Equivalent Surface Preparations*, www.wilckens-baltic.com/, Retrieved August 25, 2009, 1.05pm].

Table 2.2: SSPC Description and Equivalent Surface Preparations.

SSPC STANDARD	DESCRIPTION	EQUIVALENT
SP 1 Solvent Cleaning	Removal of oil, grease, dirt, soil, salts and contaminants by cleaning with solvent, vapour, alkali, emulsion or steam.	
SP 2 Hand Tool Cleaning	Removal of loose rust, mill scale and paint by chipping, scraping, sanding and wire brushing to a specific degree.	**ISO St 2**
SP 3 Power Tool Cleaning	Removal of loose rust, mill scale and paint by chipping, scraping, sanding and wire brushing to a specific degree.	**ISO St 3**
SP 5 White Metal Blast Cleaning	Removal of all visible rust, mill scale, paint and foreign matter by blast cleaning with wheel or nozzle (dry or wet) using sand. Grit or shot. (for very corrosive environment where high cost of cleaning is warranted)	**ISO Sa 3** BS4232 (**1st** Grade quality)
SP 6 Commercial Blast Cleaning	Blast cleaning until at least two thirds of the surface area is free of all visible residues. (for rather severe conditions of exposure)	**ISO Sa 2** BS4232 (**3rd** Grade quality)
SP 10 Near White Blast Cleaning	Blast Cleaning nearly to “White Metal” cleanliness, until at least 95% of the surface area is free of all visible residues. (For high humidity, chemical atmosphere, marine or other corrosive environments)	**ISO Sa 2.5** BS4232 (**2nd** Grade quality)

APPENDIX 2-3

Table below shows definitions of surface preparations according to ISO 8501-1. It is assumed that prior to treatment the steel surface has been cleaned of dirt and grease, and that the heavier layers of rust have been removed by chipping [*Service; Surface Preparation,* http://www.kylinpaint.com/, Retrieved August 29, 2009, 8.30pm].

Table 2.3: Description of Surface Preparation

PREPARATION BY SCRAPING AND WIRE BRUSHING	
St 2	Through scraping and wire brushing / machine brushing / grinding / etc., the treatment must remove loose mill scale, rust and foreign matter. Finally, the surface is cleaned with a vacuum cleaner, clean dry compressed air or a clean dry brush. It should that have a faint metallic sheen. The appearance must correspond to the prints designated ST 2
St 3	Very thorough scraping and wire brushing / machine brushing / grinding/ etc. Surface preparation as for St 2 but must more thoroughly treated. After removal of dust, the surface must have a pronounced metallic sheen and correspond to the prints designated St 3.

APPENDIX 3-1

Steel - Structural Plate

Steel should be cleaned by one or more of the nine surface preparations described below. These methods were originally established by the Steel Structures Council in 1952, and are used throughout the world for describing methods for cleaning structural steel. Visual standards are available through the Steel Structures Painting Council; ask for SSPC-Vis 1-67T [*Surface Preparation,* http://www.sherwin-williams.com/, Retrieved March 17, 2010, 3.47pm].

The table below provides an overview of proper surface preparation for steel substrates**.**

Table 3.1: Proper Surface Preparation for Steel.

No.	Surface Types	Preparations Steps
1	**Steel - Solvent Cleaning**	Solvent cleaning is a method for removing all visible oil, grease, soil, drawing and cutting compounds, and other soluble contaminants. Solvent cleaning does not remove rust or mill scale. Change rags and cleaning solution frequently so that deposits of oil and grease are not spread over additional areas in the cleaning process. Be sure to allow adequate ventilation.
2	**Steel - Hand Tool Cleaning**	Hand Tool Cleaning removes all loose mill scale, loose rust and other detrimental foreign matter. It is not intended that adherent mill scale, rust, and paint be removed by this process. Before hand tool cleaning, remove visible oil, grease, soluble welding residues, and salts by the methods outlined in SSPC-SP 1.

No.	Surface Types	Preparations Steps
3	**Steel - Power Tool Cleaning**	Power Tool Cleaning removes all loose mill scale, loose rust, and other detrimental foreign matter. It is not intended that adherent mill scale, rust, and paint be removed by this process. Before power tool cleaning, remove visible oil, grease, soluble welding residues, and salts by the methods outlined in SSPC-SP 1.

APPENDIX 3-2

Surface Preparation Hand and Power Tool Cleaning [*Painting Inspection – Slides,* http://www.scribd.com/, Retrieved September 28, 2009, 2.45pm]:

Table 3.2: Hand and Power Tool Cleaning

No.	**Grades of Surface Preparation**	**Comparison Picture**
1	**Hand and Power Tool Cleaning C St 2 and St 3**	
2	**Hand and Power Tool Cleaning D St 2 and St 3**	

APPENDIX 3.3: GANTT CHART for FYP I

No.	Activities	Week														
		1	2	3	4	5	6	7	8	9		10	11	12	13	14
1.	Release of FYP Topics for Selection (with no supervisor's name)	🟦○		UTP CLOSED DUE TO HIN1							MID SEM BREAK					
2.	Briefing to students on "Final Year Research Project Background"	🟦○														
3.	Submission of FYP Topics Selection (Form 02)	🟦	🟦○													
4.	Release of FYP Topics Assigned (with students and supervisor's name)		🟦													
5.	Submission of FYP Proposal		🟦○													
6.	Preliminary Research Work		🟦		🟦	🟦○										
7.	Submission of Preliminary Report					🟦○										
8.	Research Work Continuous						🟦	🟦	🟦○							
9.	Submission of Progress Report								🟦○							
10.	Seminar									🟦○						
11.	Project Work Continuous											🟦	🟦	🟦	🟦	🟦○
12.	Submission of Interim Report Final Draft														🟦○	
13.	Seminar with Internal Examiner														🟦	🟦○

Actual Progress 🟦

Key Milestone ○

APPENDIX 3.4: GANTT CHART for FYP II

No.	Activities	Week														
		1	2	3	4	5	6	7		8	9	10	11	12	13	14
1.	Sample's Preparation:- i. Cutting steel plate	■	■	■	■				MID SEM BREAK							
	ii. Drill hole at center of plate	■	■	■	■											
	iii. Surface preparation	■	■	■	■											
	iv. Measure plate	■	■	■	■											
	v. Inspection with the surface profiler	■	■	■	■○											
2.	Submission of Progress Report 1					■○										
3.	Project Work Continues:- i. Coating process					■	■	■								
	ii. Measure plate					■	■	■								
	iii. Inspection with the surface profiler					■	■	■								
	iv. Testing with the Taber Abrader Machine					■	■	■○								
	v. Measure plate after testing with the Taber Abrader Machine							■		■						
	vi. Inspection with the surface profiler							■		■○						
4.	Submission of Progress Report 2									■○						
5.	Seminar									■○						
6.	Project Work Continues:- vii. Analyze the experiment - Checking under SEM														■○	
7.	Poster Exhibition												■○			

8.	Submission of Dissertation Final Draft															🟦 ○
9.	Oral Presentation									🟦 **During study week**						
10.	Submission of Dissertation (Hard Bound)									🟦 **7 days after oral presentation**						

Actual Progress 🟦

Key Milestone ○

APPENDIX 4-1

Data from surface profiler machine:

Average Roughness: The average distance between peaks and valleys of surface roughness.

4.1 Surface roughness of the steel plate ***before surface preparation***:

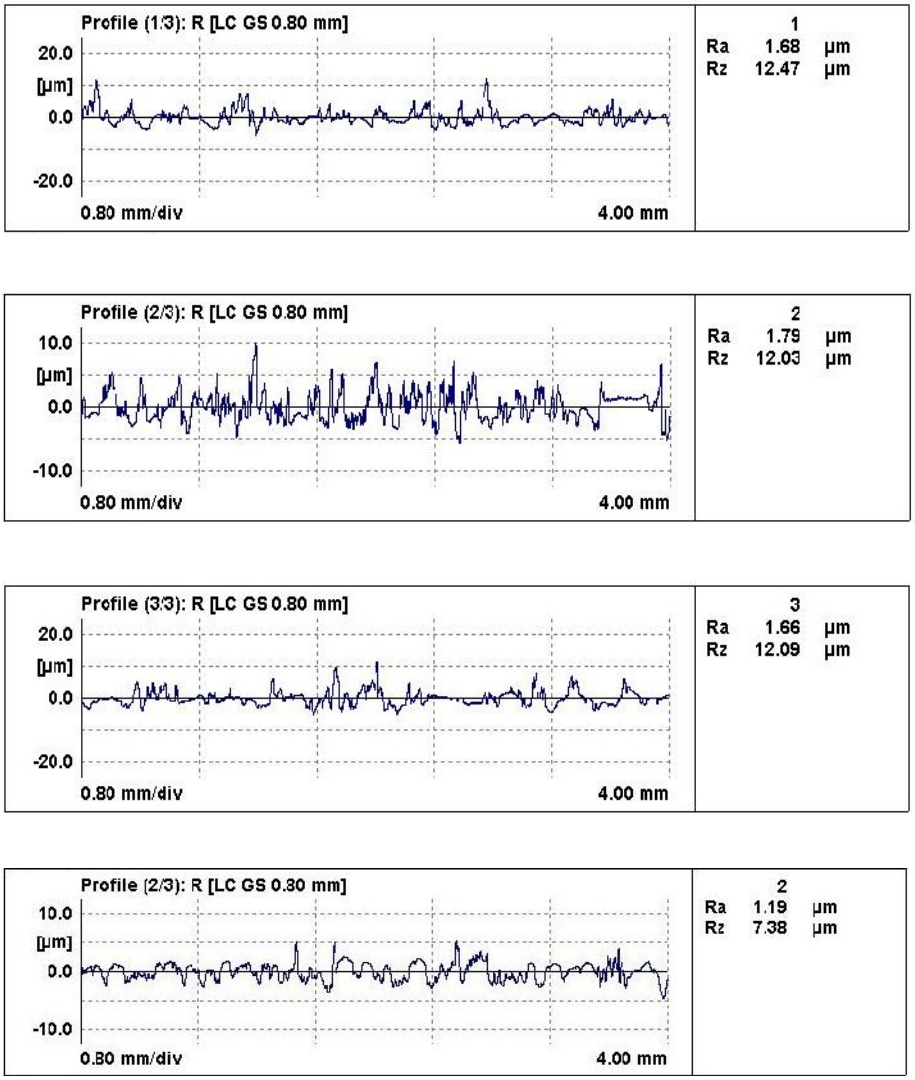


Figure 4.1: Surface roughness before surface preparation

4.2 Surface roughness of the steel plate ***after surface preparation***:

4.2.1 Solvent Cleaning (SP 1)

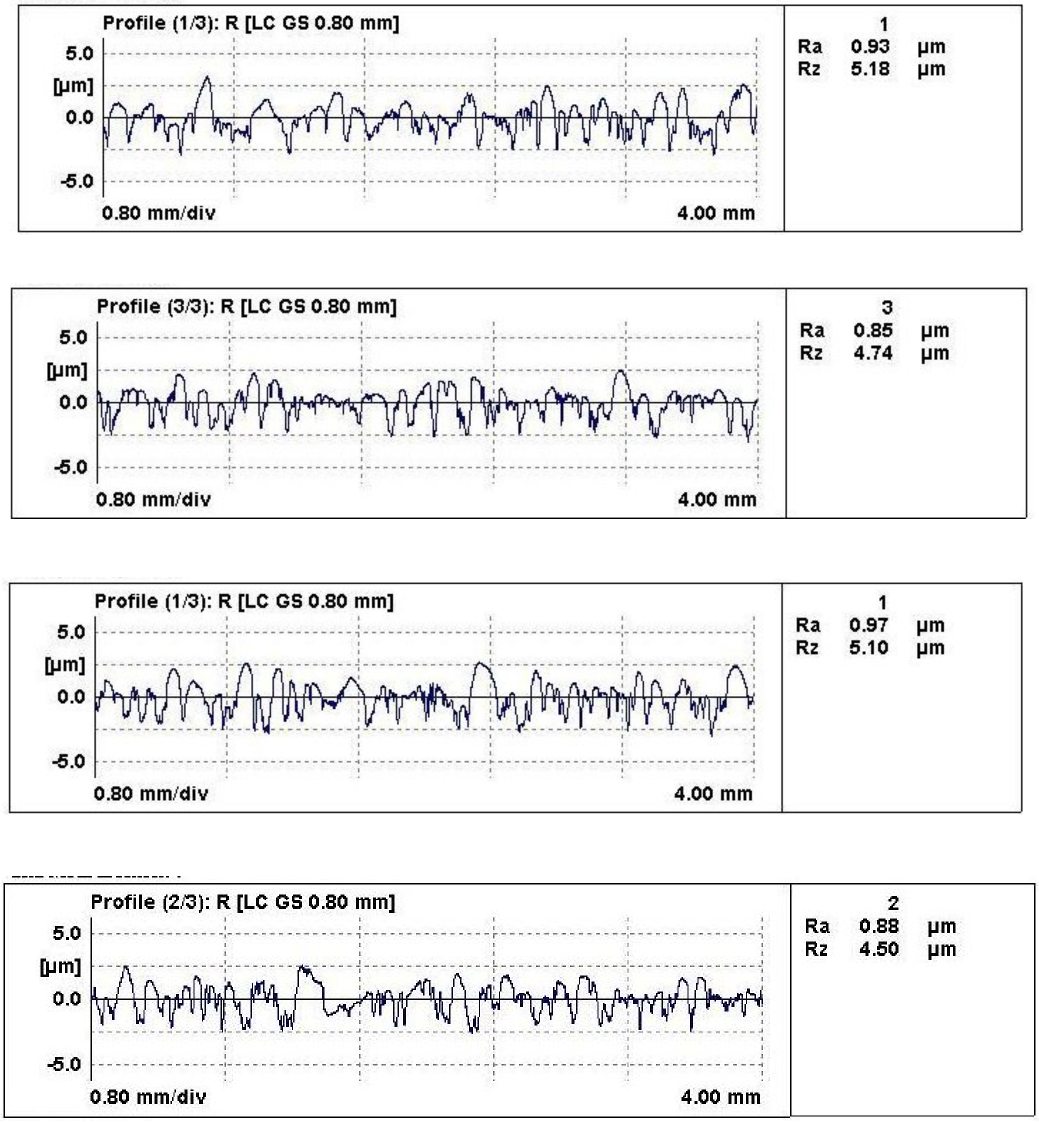


Figure 4.2: Comparison between 4 measurements – Solvent cleaning (SP 1)

4.2.2 Hand and Power Tool Cleaning (St 3)

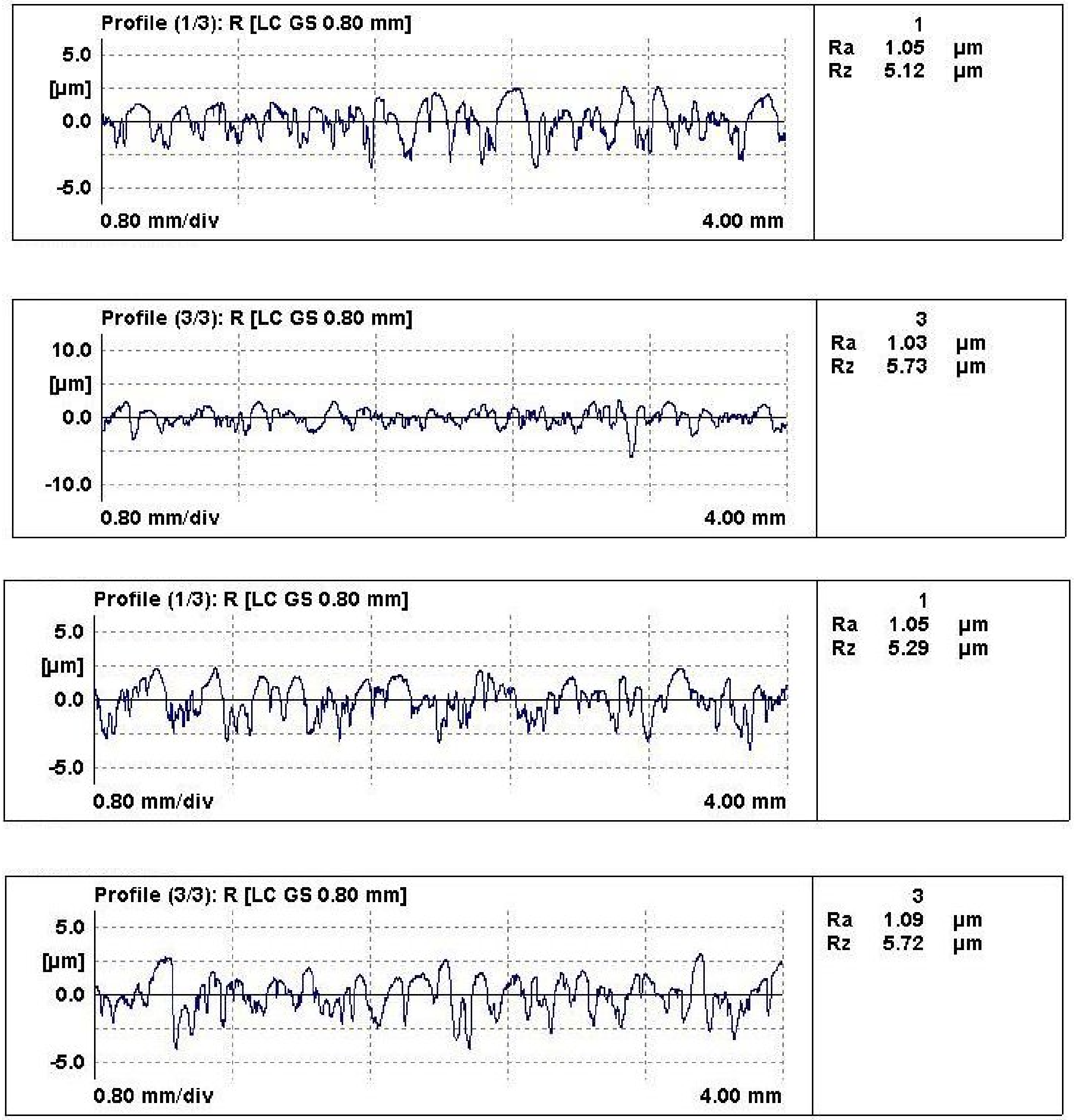


Figure 4.3: Comparison between 4 measurements – Hand and Power Tool cleaning (St 3)

4.3 Surface roughness of the steel plate ***after coating***:

4.3.1 Solvent Cleaning (SP 1)

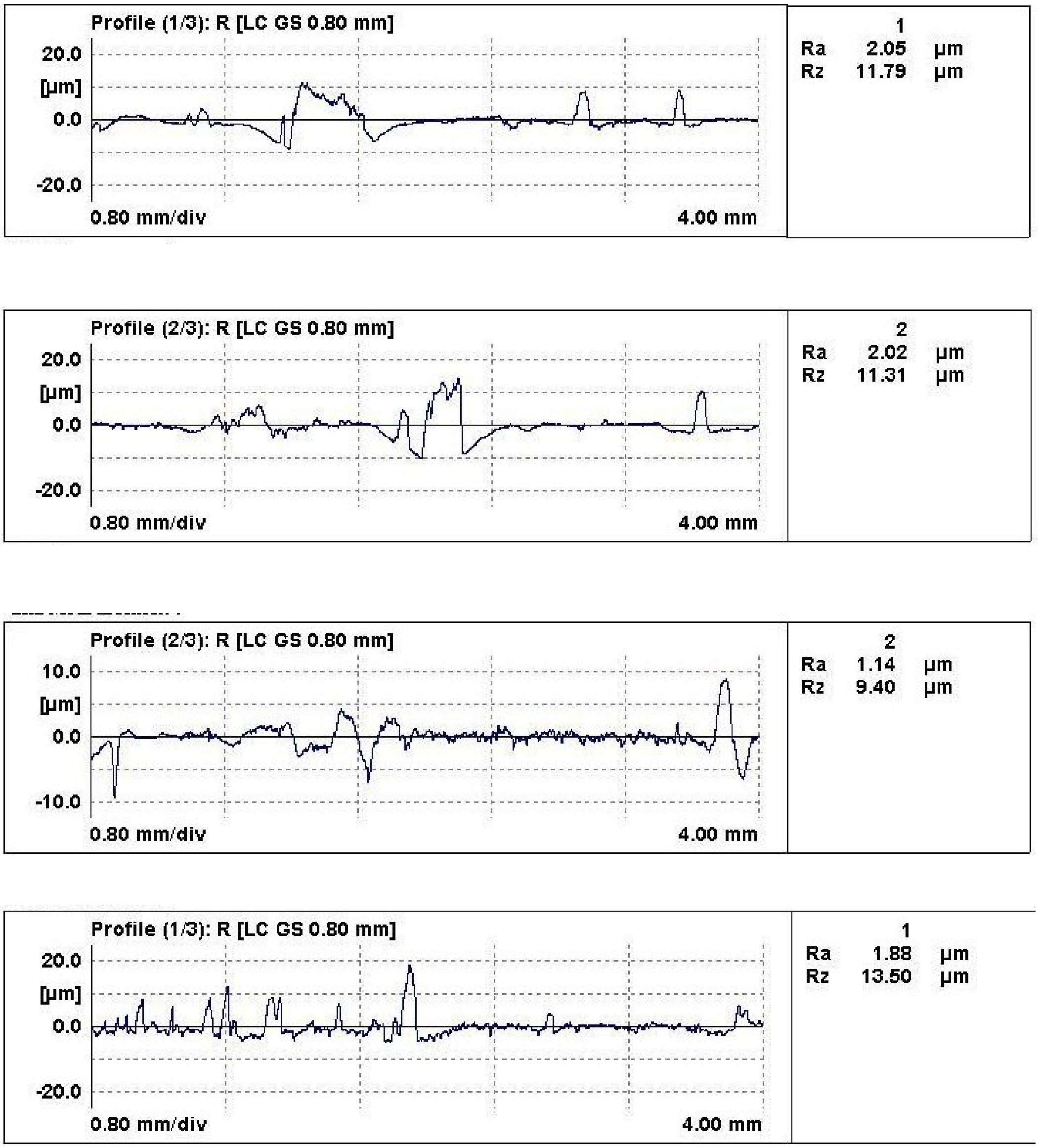
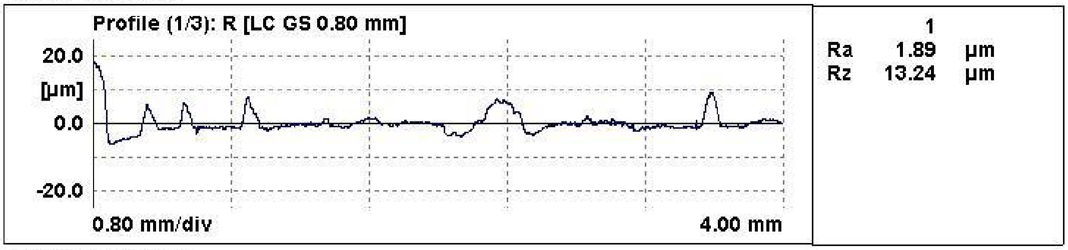


Figure 4.4: Comparison between 4 measurements – Solvent cleaning (SP 1)

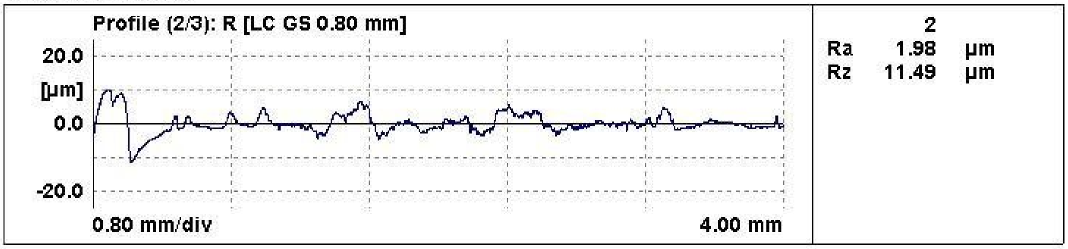
4.3.2 Hand and Power Tool Cleaning (St 3)

1st Measurement :



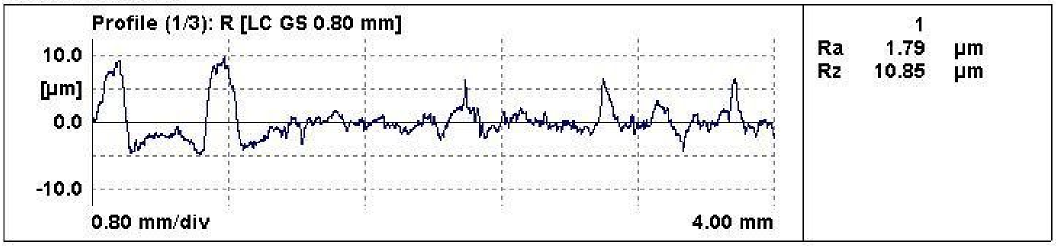
1
Ra 1.89 µm
Rz 13.24 µm

2nd Measurement :



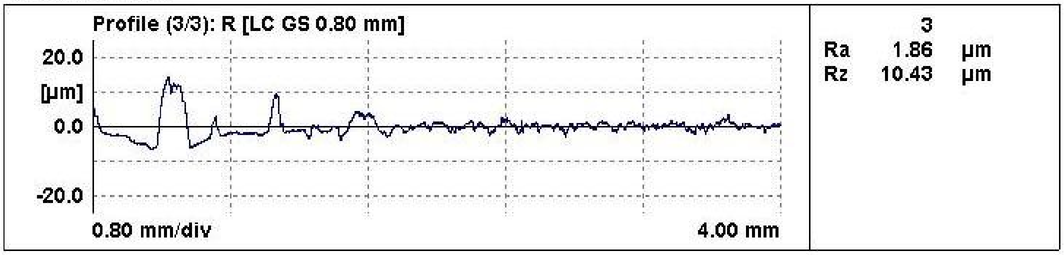
2
Ra 1.98 µm
Rz 11.49 µm

1st Measurement :



1
Ra 1.79 µm
Rz 10.85 µm

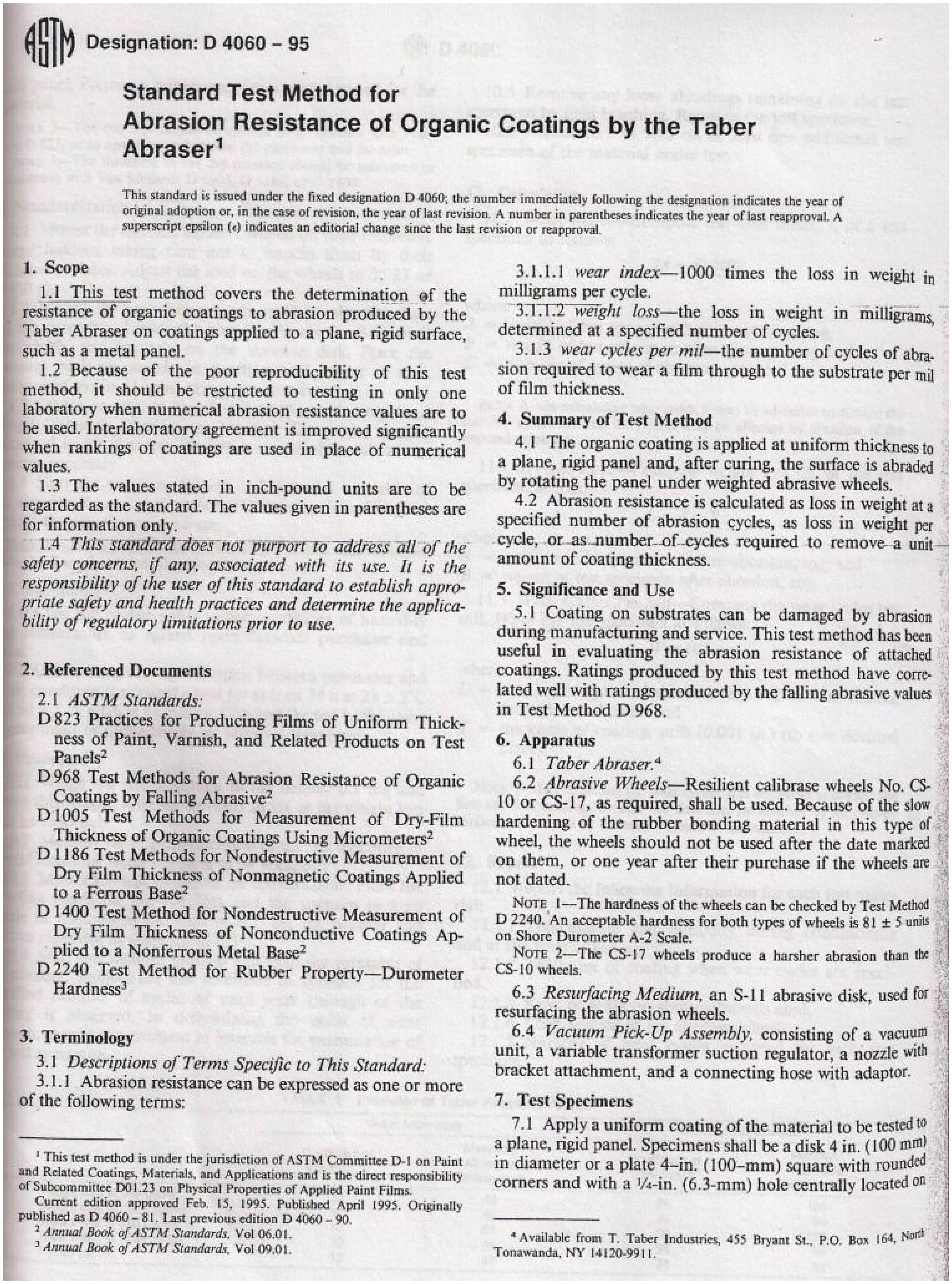
3rd Mesurement :



3
Ra 1.86 µm
Rz 10.43 µm

Figure 4.5: Comparison between 4 measurements – Hand and Power Tool cleaning (St 3)

APPENDIX 4-2



Designation: D 4060 – 95

Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser[1]

This standard is issued under the fixed designation D 4060; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the resistance of organic coatings to abrasion produced by the Taber Abraser on coatings applied to a plane, rigid surface, such as a metal panel.

1.2 Because of the poor reproducibility of this test method, it should be restricted to testing in only one laboratory when numerical abrasion resistance values are to be used. Interlaboratory agreement is improved significantly when rankings of coatings are used in place of numerical values.

1.3 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 823 Practices for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels[2]

D 968 Test Methods for Abrasion Resistance of Organic Coatings by Falling Abrasive[2]

D 1005 Test Methods for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers[2]

D 1186 Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base[2]

D 1400 Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base[2]

D 2240 Test Method for Rubber Property—Durometer Hardness[3]

3. Terminology

3.1 *Descriptions of Terms Specific to This Standard:*

3.1.1 Abrasion resistance can be expressed as one or more of the following terms:

3.1.1.1 *wear index*—1000 times the loss in weight in milligrams per cycle.

3.1.1.2 *weight loss*—the loss in weight in milligrams, determined at a specified number of cycles.

3.1.3 *wear cycles per mil*—the number of cycles of abrasion required to wear a film through to the substrate per mil of film thickness.

4. Summary of Test Method

4.1 The organic coating is applied at uniform thickness to a plane, rigid panel and, after curing, the surface is abraded by rotating the panel under weighted abrasive wheels.

4.2 Abrasion resistance is calculated as loss in weight at a specified number of abrasion cycles, as loss in weight per cycle, or as number of cycles required to remove a unit amount of coating thickness.

5. Significance and Use

5.1 Coating on substrates can be damaged by abrasion during manufacturing and service. This test method has been useful in evaluating the abrasion resistance of attached coatings. Ratings produced by this test method have correlated well with ratings produced by the falling abrasive values in Test Method D 968.

6. Apparatus

6.1 *Taber Abraser.*[4]

6.2 *Abrasive Wheels*—Resilient calibrase wheels No. CS-10 or CS-17, as required, shall be used. Because of the slow hardening of the rubber bonding material in this type of wheel, the wheels should not be used after the date marked on them, or one year after their purchase if the wheels are not dated.

NOTE 1—The hardness of the wheels can be checked by Test Method D 2240. An acceptable hardness for both types of wheels is 81 ± 5 units on Shore Durometer A-2 Scale.

NOTE 2—The CS-17 wheels produce a harsher abrasion than the CS-10 wheels.

6.3 *Resurfacing Medium,* an S-11 abrasive disk, used for resurfacing the abrasion wheels.

6.4 *Vacuum Pick-Up Assembly,* consisting of a vacuum unit, a variable transformer suction regulator, a nozzle with bracket attachment, and a connecting hose with adaptor.

7. Test Specimens

7.1 Apply a uniform coating of the material to be tested to a plane, rigid panel. Specimens shall be a disk 4 in. (100 mm) in diameter or a plate 4–in. (100–mm) square with rounded corners and with a ¼-in. (6.3-mm) hole centrally located on

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[1] This test method is under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.23 on Physical Properties of Applied Paint Films.

Current edition approved Feb. 15, 1995. Published April 1995. Originally published as D 4060 – 81. Last previous edition D 4060 – 90.

[2] *Annual Book of ASTM Standards,* Vol 06.01.

[3] *Annual Book of ASTM Standards,* Vol 09.01.

[4] Available from T. Taber Industries, 455 Bryant St., P.O. Box 164, North Tonawanda, NY 14120-9911.

each panel. Prepare a minimum of two coated panels for the material.

NOTE 3—The coatings should be applied in accordance with Practices D 823, or as agreed upon between the purchaser and the seller.

NOTE 4—The thickness of the dry coatings should be measured in accordance with Test Methods D 1005, D 1186, or D 1400.

8. Standardization

8.1 Mount the selected abrasive wheels on their respective flange holders, taking care not to handle them by their abrasive surfaces. Adjust the load on the wheels to 35.27 oz (1000 g).

8.2 Mount the resurfacing medium (S-11 abrasive disk) on the turntable. Lower the abrading heads carefully until the wheels rest squarely on the abrasive disk. Place the vacuum pick-up nozzle in position and adjust it to a distance of 1⁄32 in. (1 mm) above the abrasive disk.

8.3 Set the counter to "zero" and set the suction regulator to approximately 50 points on the dial. The setting may be increased to 90 if more effective removal of the abradings appears necessary.

8.4 Start the vacuum pick-up and then the turntable of the abrader. Resurface the wheels by running them 50 cycles against the resurfacing medium.

NOTE 5—The wheels should be resurfaced in this manner before esting each specimen and after every 500 cycles.

. Conditioning

9.1 Cure the coated panel under conditions of humidity nd temperature as agreed upon between purchaser and eller.

9.2 Unless otherwise agreed upon between purchaser and eller, condition the coated panel for at least 24 h at 23 ± 2°C nd 50 ± 5 % relative humidity. Conduct the test in the same nvironment or immediately on removal therefrom.

0. Procedure

10.1 Weigh the test specimen to the nearest 0.1 mg and ecord this weight, if either the wear index or the weight loss s to be reported.

10.2 Measure the coating thickness of the test specimen in veral locations along the path to be abraded.

10.3 Mount the test specimen on the turntable. Place the rading heads on the test film and the vacuum pick-up ozzle in position as outlined in 8.2. Set the counter and ction regulator as outlined in 8.3.

10.4 Start the vacuum pick-up and then the turntable of e abrader. Subject the test specimen to abrasion for the ecified number of cycles or until wear through of the ating is observed. In determining the point of wear ough, stop the instrument at intervals for examination of e test specimen.

10.5 Remove any loose abradings remaining on the test specimen by light brushing. Reweigh the test specimen.

10.6 Repeat 10.1 to 10.5 on at least one additional test specimen of the material under test.

11. Calculation

11.1 *Wear Index*—Compute the wear index, I, of a test specimen as follows:

$$I = \frac{(A - B)\,1000}{C}$$

where:

A = weight of test specimen before abrasion, mg,
B = weight of test specimen after abrasion, mg, and
C = number of cycles of abrasion recorded.

NOTE 6—In calculating wear index it may be advisable to discard the last 200 cycles because the results may be affected by abrasion of the exposed substrate.

11.2 *Weight Loss*—Compute weight loss, L, of the test specimen as follows:

$$L = A - B$$

where:

A = weight of test specimen before abrasion, mg, and
B = weight of test specimen after abrasion, mg.

11.3 *Wear Cycles Per Mil*—Compute the wear cycles per mil, W, of the test specimen as follows:

$$W = D/T$$

where:

D = number of cycles of abrasion required to wear coating through to substrate and
T = thickness of coating, mils (0.001 in.) (to one decimal place).

NOTE 7—In calculating the wear cycles, it is advisable to discard the first and last readings because the first may be affected by an uneven surface and the last by abrasion of parts of the substrate.

12. Report

12.1 Report the following information for each test material:

12.1.1 Temperature and humidity during conditioning and at the time of testing,

12.1.2 Thickness of coating when wear cycles are specified,

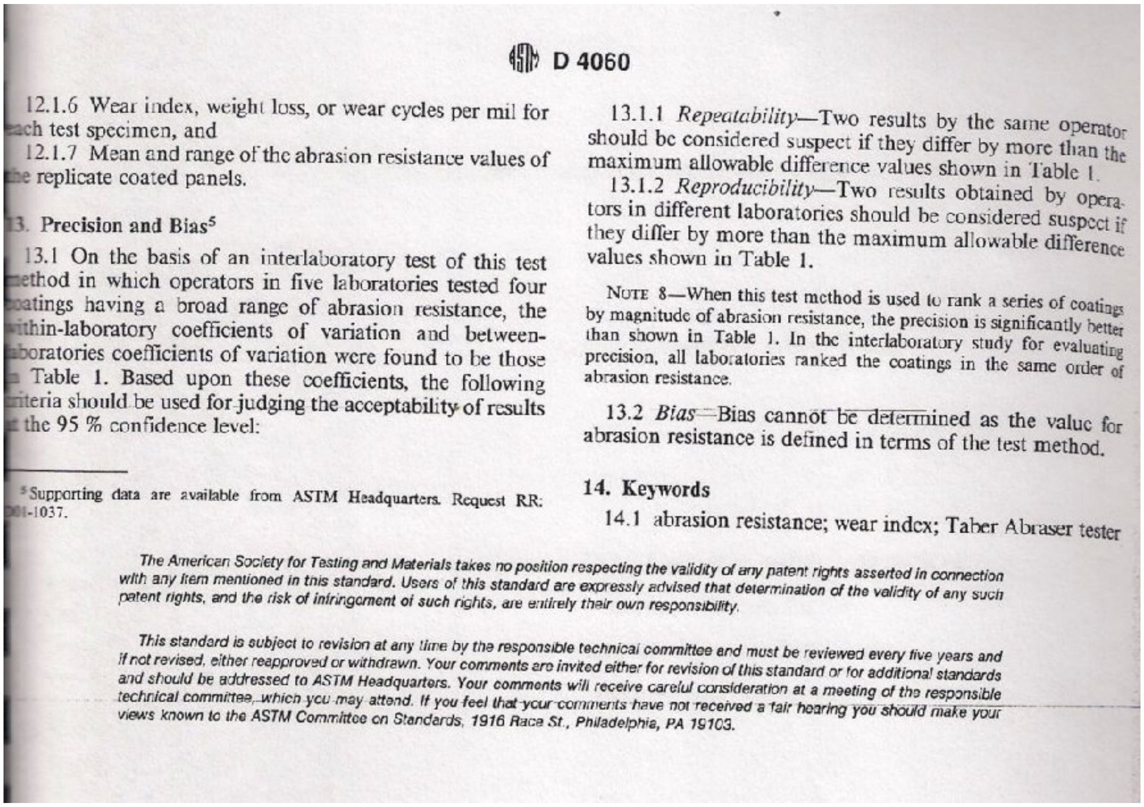
12.1.3 Kind of calibrase abrasive wheels used,

12.1.4 Load applied to the abrasive wheels,

12.1.5 Number of wear cycles recorded for each test specimen,

TABLE 1 Precision of Taber Abrasion Values

	Within Laboratory		Between Laboratories	
	Coefficient of Variation, %	Maximum Allowable Difference, %	Coefficient of Variation, %	Maximum Allowable Difference, %
Weight loss at 500 cycles	12	48	36	105
Weight loss at 1000 cycles	10	46	30	90
Wear index at 500 cycles	13	52	36	106
Wear index at 1000 cycles	10	46	30	92
Cycles per mil	13	44	31	92



12.1.6 Wear index, weight loss, or wear cycles per mil for ach test specimen, and

12.1.7 Mean and range of the abrasion resistance values of e replicate coated panels.

3. Precision and Bias[5]

13.1 On the basis of an interlaboratory test of this test ethod in which operators in five laboratories tested four oatings having a broad range of abrasion resistance, the ithin-laboratory coefficients of variation and between-boratories coefficients of variation were found to be those Table 1. Based upon these coefficients, the following iteria should be used for judging the acceptability of results the 95 % confidence level:

13.1.1 *Repeatability*—Two results by the same operator should be considered suspect if they differ by more than the maximum allowable difference values shown in Table 1.

13.1.2 *Reproducibility*—Two results obtained by operators in different laboratories should be considered suspect if they differ by more than the maximum allowable difference values shown in Table 1.

NOTE 8—When this test method is used to rank a series of coatings by magnitude of abrasion resistance, the precision is significantly better than shown in Table 1. In the interlaboratory study for evaluating precision, all laboratories ranked the coatings in the same order of abrasion resistance.

13.2 *Bias*—Bias cannot be determined as the value for abrasion resistance is defined in terms of the test method.

14. Keywords

14.1 abrasion resistance; wear index; Taber Abraser tester

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[5] Supporting data are available from ASTM Headquarters. Request RR: -1037.